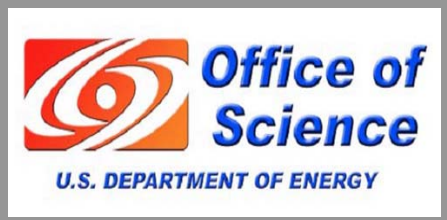
Collider-Accelerator Department Activities

DOE Nuclear Physics Program Review

Derek I. Lowenstein

July 9, 2003



Outline

- C-A DEPARTMENT
- RHIC
  - IONS
  - POLARIZED PROTONS
- OTHER PROGRAMS
  - AGS
  - TANDEM
  - LINAC
  - CIRC CONSTRUCTION PROJECT PROPOSAL
  - NASA SPACE RADIATION LABORATORY (NSRL)
  - SNS CONSTRUCTION PROJECT

C-AD MISSION

- "To develop, improve and operate the suite of particle/heavy ion accelerators used to carry out the program of accelerator-based experiments at BNL; support of the experimental program including design, construction and operation of the beam transports to the experiments, plus support of detector and research needs of the experiments; to design and construct new accelerator facilities in support of the BNL and national missions. The C-A Department supports an international user community of over 1500 scientists. The Department performs all these functions in an environmentally responsible and safe manner under a rigorous conduct of operations approach."

Facilities: Principal facilities of C-AD comprise of:

2 x 15MV Tandems

750 keV RFQ linac

200 MeV proton linac

5 GeV/c Booster

30 GeV AGS

2 x 250 GeV RHIC rings

3 GeV /c muon storage ring

640,000 $ft.^2$ accelerator areas

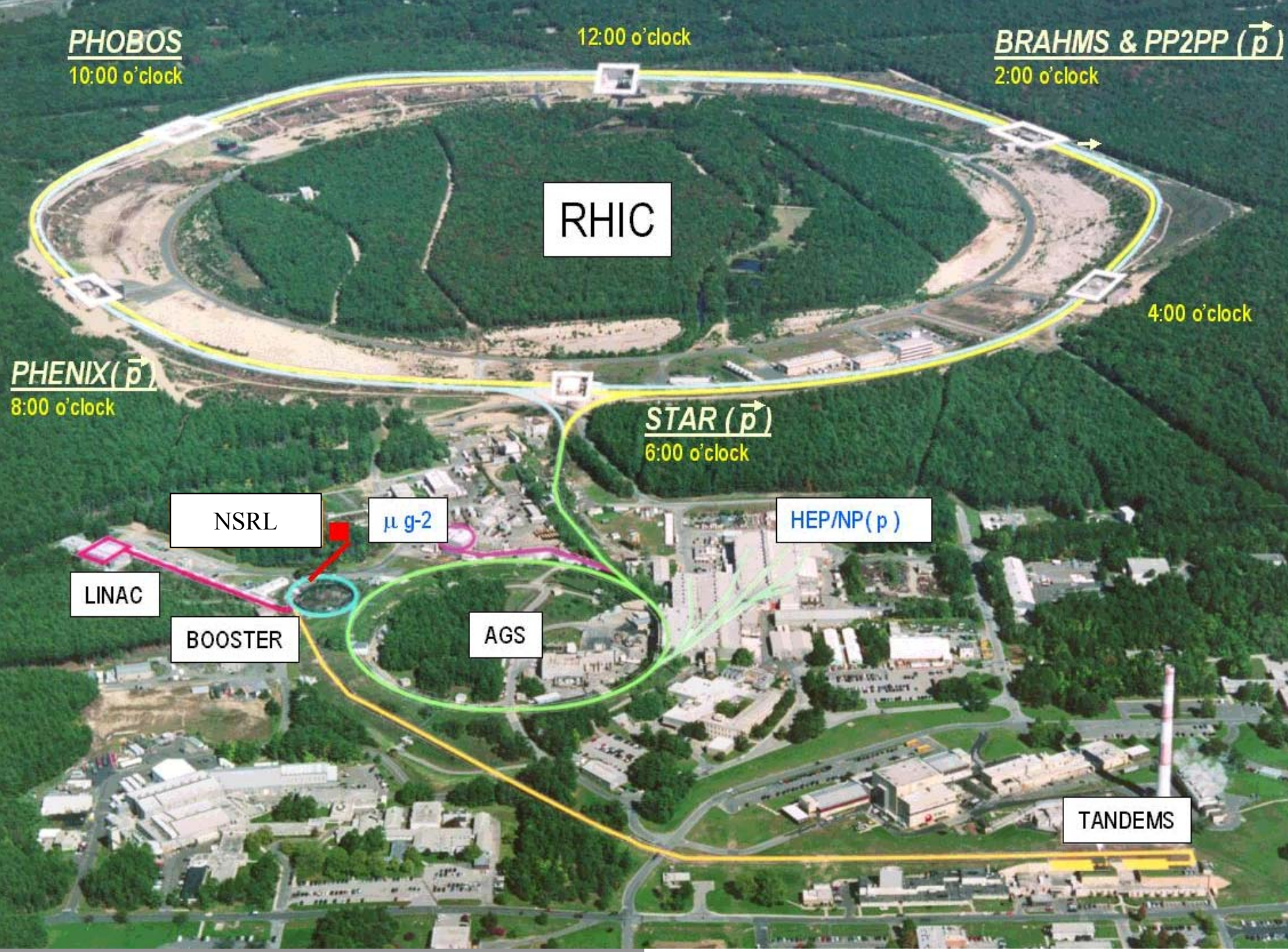
140,000 $ft.^2$ experimental areas

190,000 $ft.^2$ general office/laboratory space

145,000 $ft.^2$ high-bay work space

80,000 $ft.^2$ storage/materials handling space

Research Library and 190 seat auditorium


PHOBOS
10:00 o'clock
12:00 o'clock
BRAHMS & PP2PP ($\vec{p}$)
2:00 o'clock
RHIC
4:00 o'clock
PHENIX($\vec{p}$)
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
NSRL
μ g-2
HEP/NP(p)
LINAC
BOOSTER
AGS
TANDEMS

Collider-Accelerator Department (C-AD)

- C-AD is the single largest entity at BNL
  - $130M department with ~500 FTEs:
    - ~ $96M in Nuclear Physics – DOE
    - ~ $28M in Materials Sciences – DOE
    - ~ $5M in Radiobiology – NASA
    - ~ $1M in Other Related Programs

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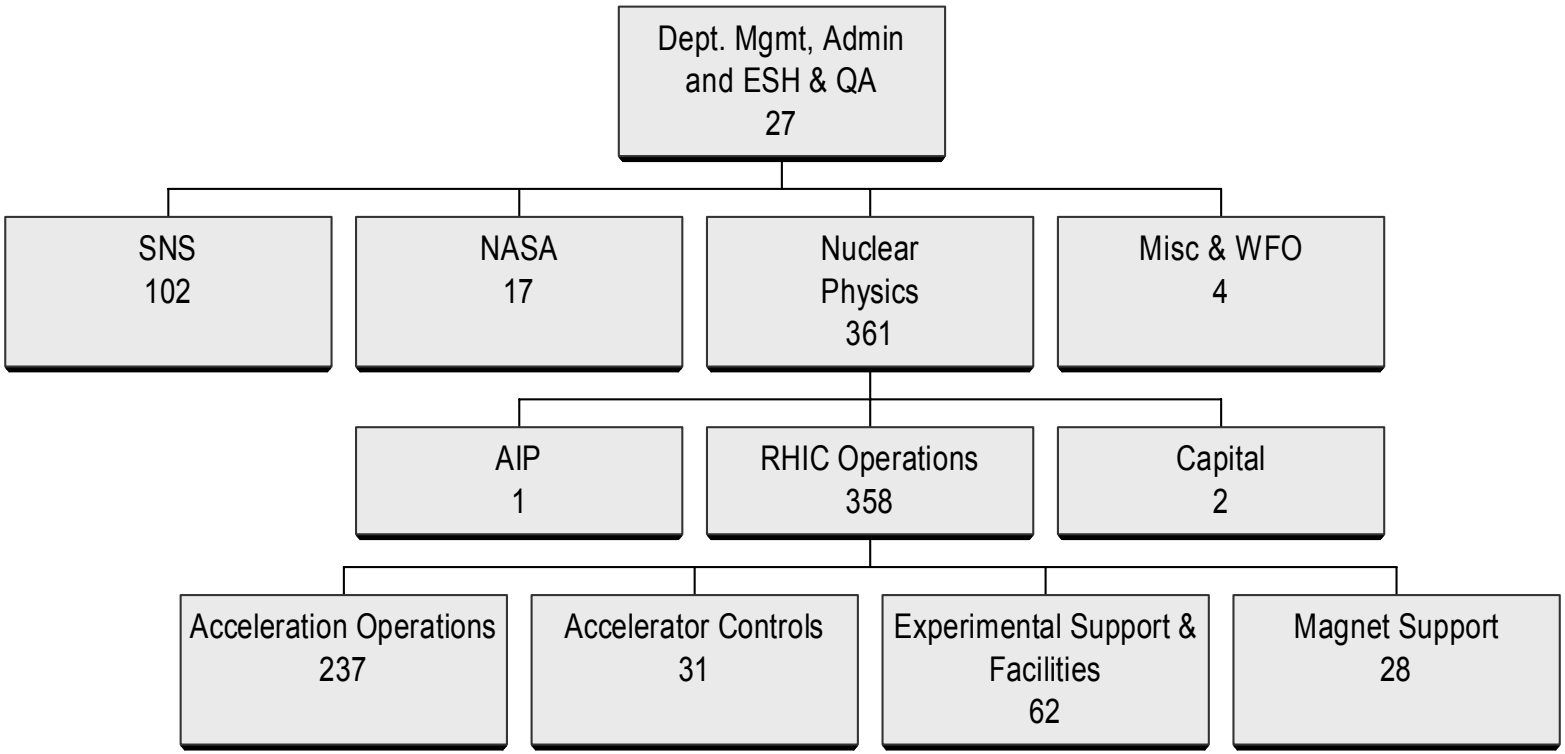
Collider Accelerator Department

(Programmatic FTEs 511*)



* Reflects Trim #3 FTE Data circa May 2003

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C-AD PROGRAM AREAS

- **RHIC**
  - Heavy Ion (DOE-NP)
  - Polarized Proton (DOE-NP)

C-AD Major Programmatic Area Nuclear Physics

	FY 2002	FY 2003	President's FY 2004	Contractor's Revised FY 2004	Proposed FY 2005
Heavy Ion Physics					
RHIC Operations	$72,223 *	$84,400 *	$86,132	$98,350	$102,840
RHIC Capital	1,100	1,100	1,200	2,150	2,200
RHIC AIP	2,500	2,900	2,900	3,000	3,300
Total RHIC OPS	$75,823	$88,400	$90,232	$103,500	$108,340
Effort - FTE	*301*	*330*	*323*	*350*	*349*
RHIC/C-AD Exp. Sup.	$6,460	$7,438	$7,258	$8,100	$8,385
RHIC/C-AD Capital	1,200	400	600	600	410
Total Exp. Support	$7,660	$7,838	$7,858	$8,700	$8,795
Effort - FTE	*30*	*31*	*31*	*31*	*31*
Total RHIC C-AD	$83,483	$96,238 +	$98,090	$112,200	$117,135
Effort - FTE	*331*	*361*	*354*	*381*	*380*
Operations weeks	17	31	27	37	37

*Includes $1M LIPA Energy Credit

+ First year of waste management funding @ $3.1M

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BUDGET COMMENTS

- Running time
  - physics demand and machine development time ⇒ maximize run weeks for ion and polarized proton programs
  - gave up capital funds to get to 29 weeks after Omnibus reduction in FY2003
  - reduced staff by 20 persons during FY2003, after growing the staff size to meet maintenance and operations needs
  - RHIC staffing level is too small to reach the minimum availability level of 80%. A complex of 8 accelerators with tens of thousands of control points.
- Reliability Performance
  - reliability in FY2003 was below 80%
  - manpower level and purchasing power too small
- Accelerator R&D
  - electron-cooling projected to need $5M to complete R&D
  - DOE NP + US Navy, LDRD augmentation in FY2003
- Waste management
  - BNL has yet to respond to C-A memorandum

Why is RHIC Operations So Challenging?

- Unlike other colliders that run a single combination of species at a fixed energy, RHIC must be capable of:
  - providing ion beams from protons to gold
  - at a range of energies from 10 GeV to 250 GeV
  - like and unlike species collisions
  - polarized protons; requires the highest level of accelerator physics and engineering sophistication
- FY2001+2002 (Run 2) operations of 31 weeks
  - combined FY01 and FY02 runs due to budget shortfall
  - gold - gold @ 10, 65, 100 GeV / nucleon
  - polarized protons @ 100 GeV / nucleon, transverse polarization
- FY2003(Run 3) RHIC operated for 31 weeks
  - deuterons - gold @ 100 GeV / nucleon
  - polarized protons @ 100 GeV / nucleon, longitudinal polarization
- FY2004 (Run 4) will operate for 27 weeks, species to be determined

RHIC Machine/Detector Planning Meeting 3 June 2003 (archive)

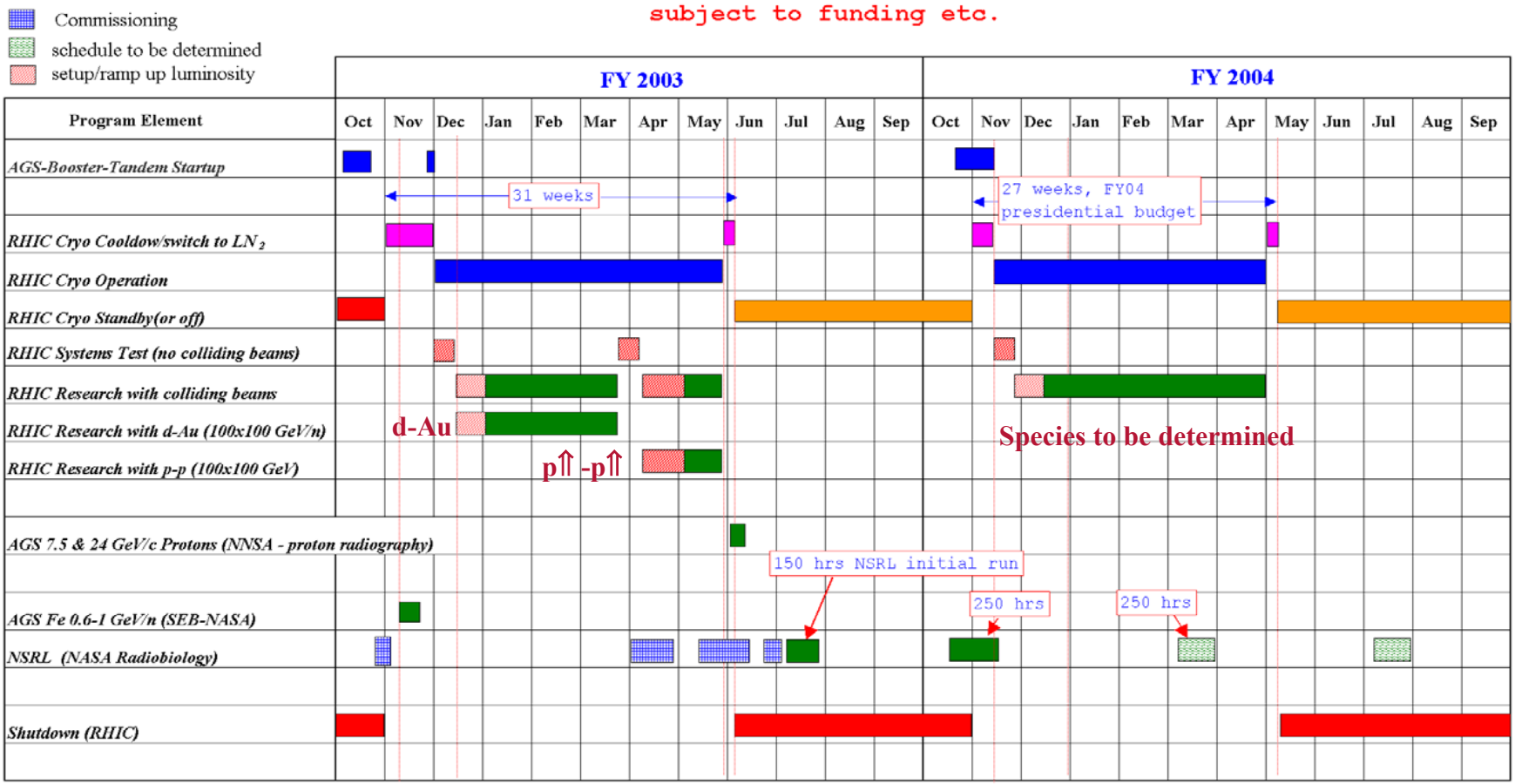
- **Details – as run**
  - 1 Nov 02 - Cryo on
  - 2 Dec 02 – Blue Ring Cold
  - 3 Dec 02 – "2 week" setup w/o colliding beams begins
  - 9 Dec 02 – Yellow Cold
  - 23 Dec 02 – first collisions at store, "3 week" setup with colliding beams begins
  - 12 Jan 03 – Physics with 100 GeV/n x 100 GeV/n d-Au begins (9 days late)
  - 24 Mar 03 – *Revised:* end of d-Au run *(this shortened the pp run by 3 days)*
  - 24 Mar 03 – begin "5 week" pp setup
  - 3 May 03 – begin "3 week" physics run
  - 19 May 03 – begin "40" hour pp2pp physics run @ ~ 2000 hrs
  - 21 May 03 – end pp2pp run (2240 hrs)
  - 23 May 03 – BRAHMS and PHOBOS runs end, switch to 2 IR running condition
  - 30 May 03 – 8 hour beam experiments (began @ 0800 hrs)
  - 6 June 03 – cryo warm-up ends, end of 31 weeks RHIC operations

http://server.c-ad.bnl.gov/esfd

C-A Operations-FY03-04

27 June 03

subject to funding etc.



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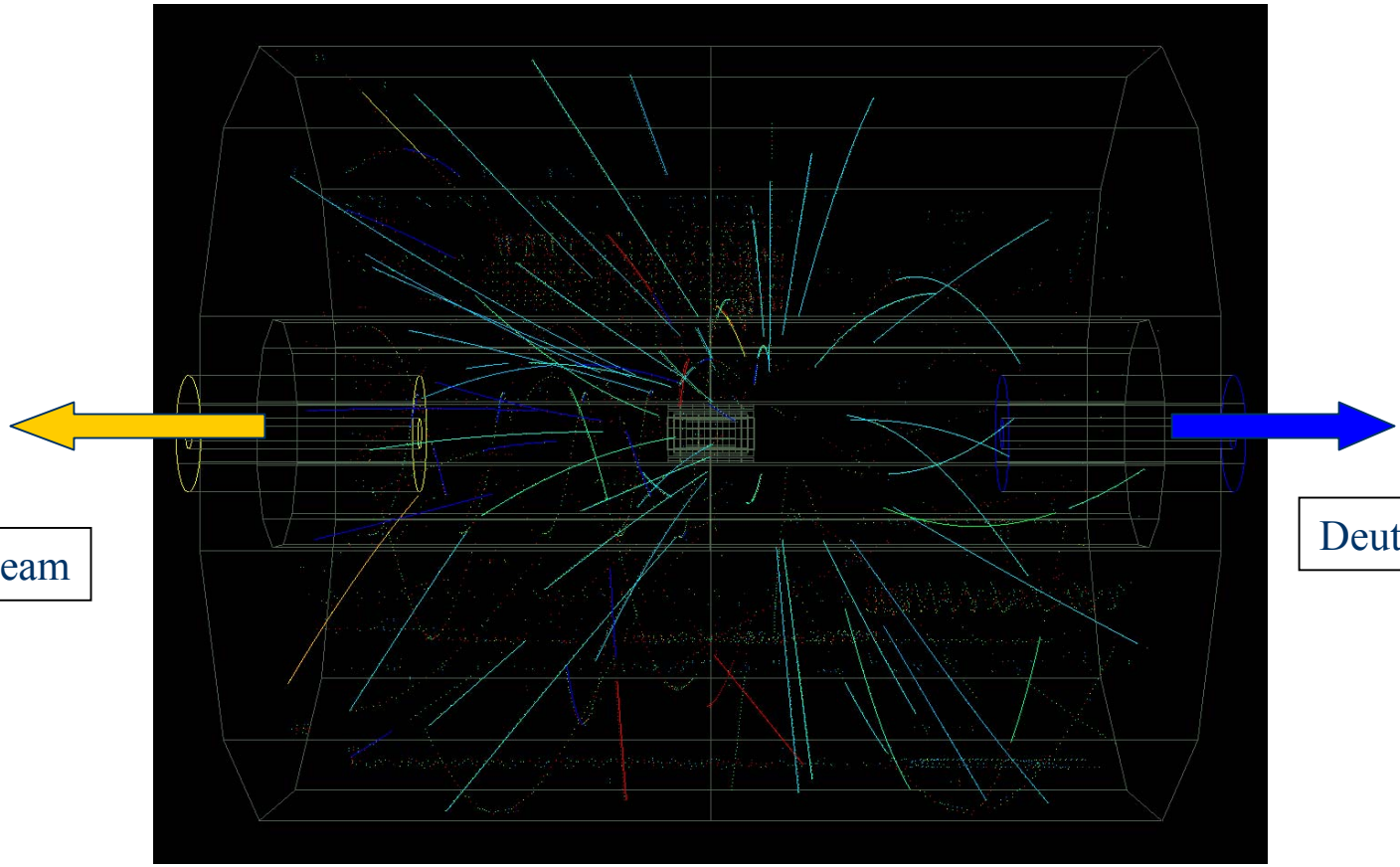
Deuteron-Gold Collision Event at RHIC
Seen in STAR Time Projection Chamber, Jan. 11, 2003



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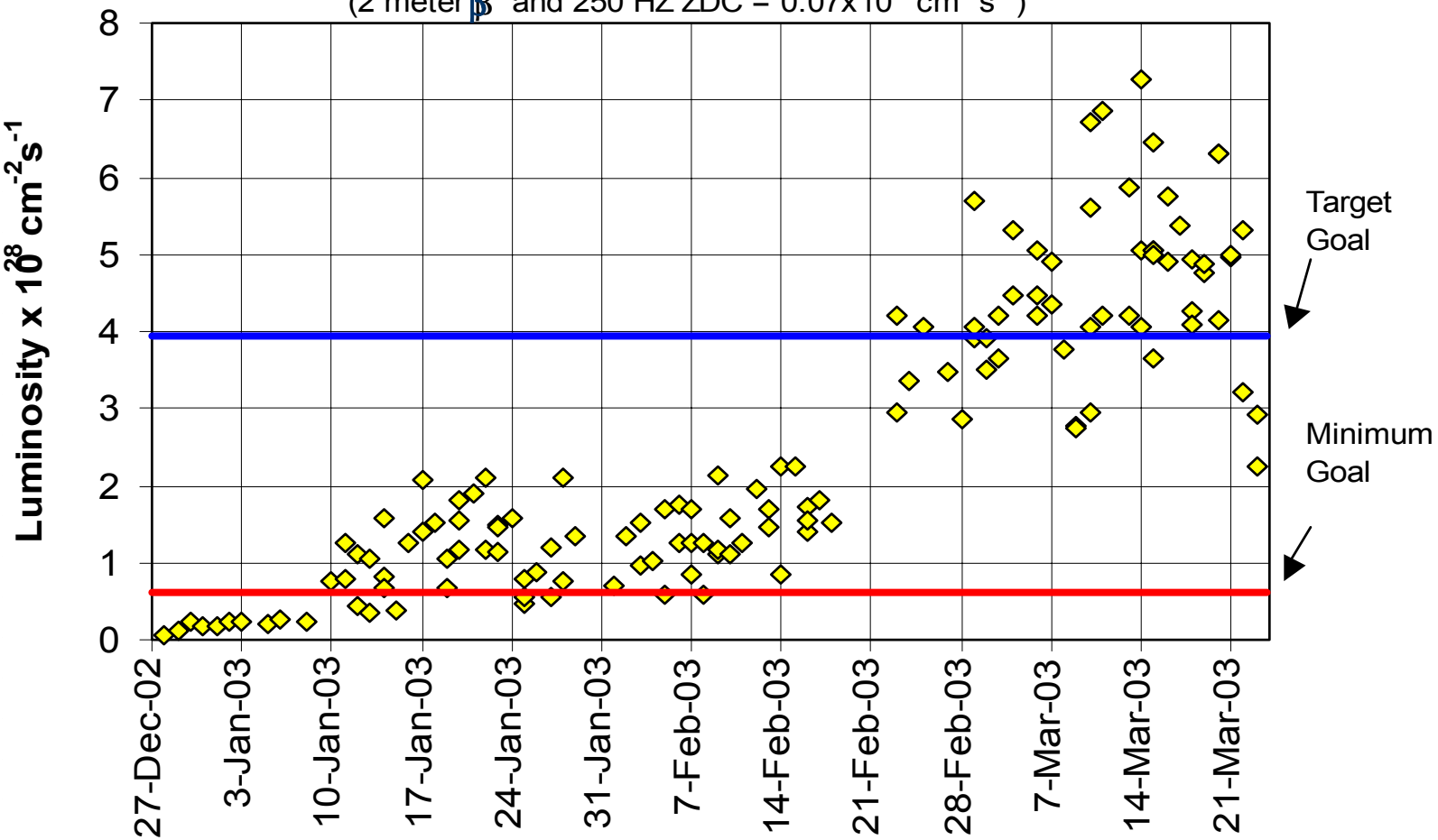
RHIC Beam Max. Luminosity at beginning of store
FY 2003 (100 GeV/n d x 100 GeV/n Au)

(2 meter β^* and 250 HZ ZDC = $0.07 \times 10^{28} cm^{-2} s^{-1}$)



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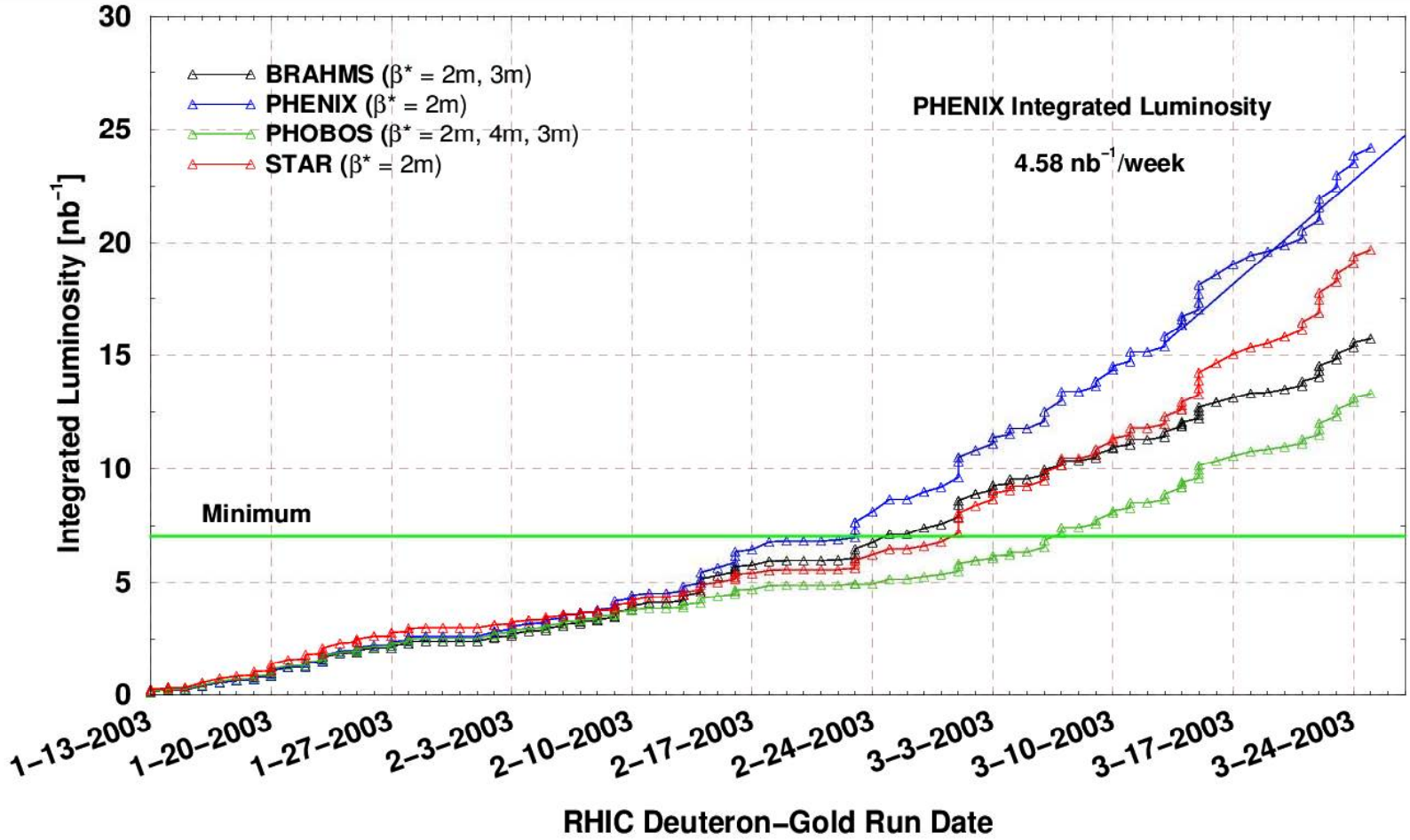

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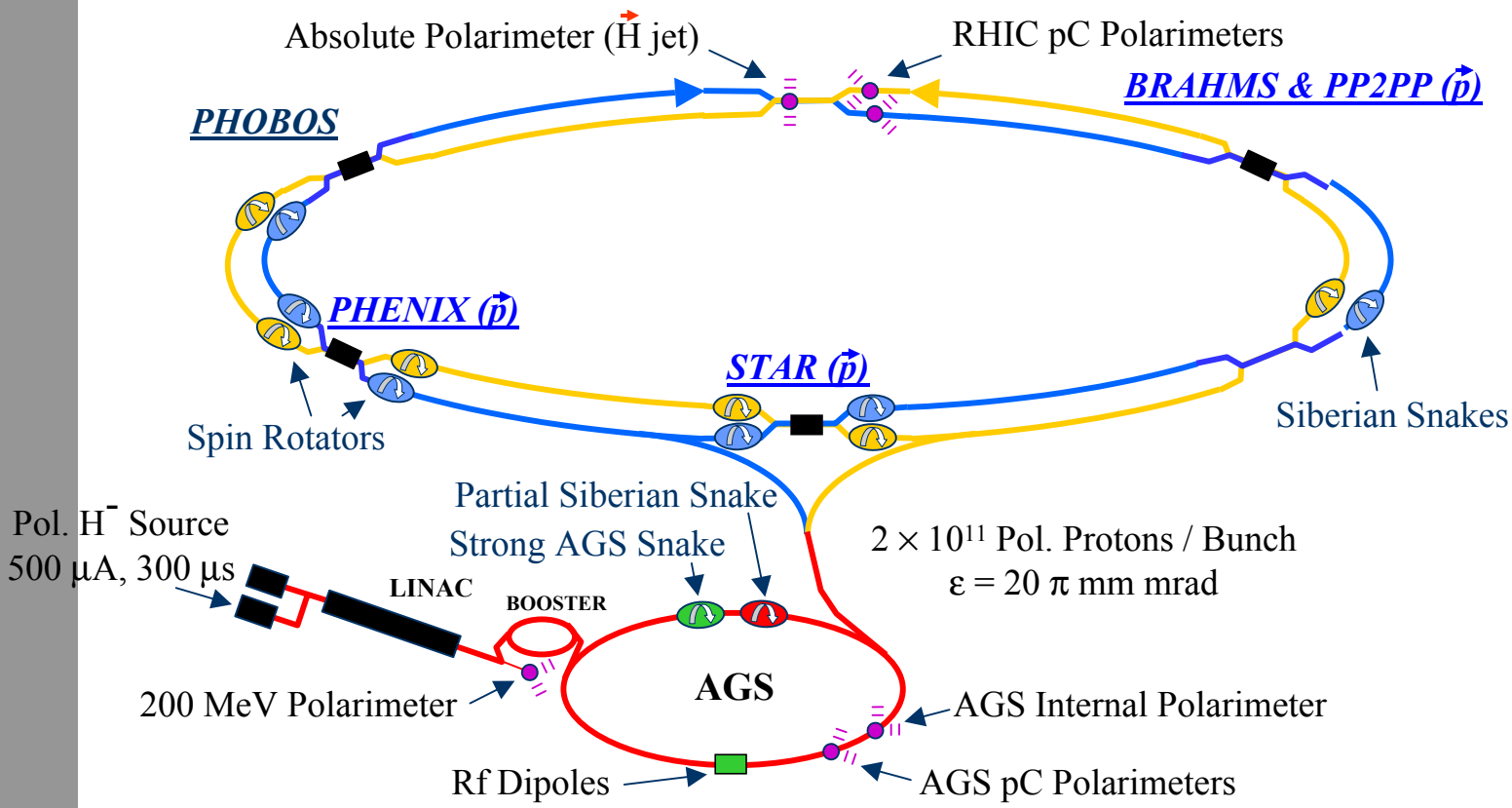
Polarized Proton Collisions in RHIC



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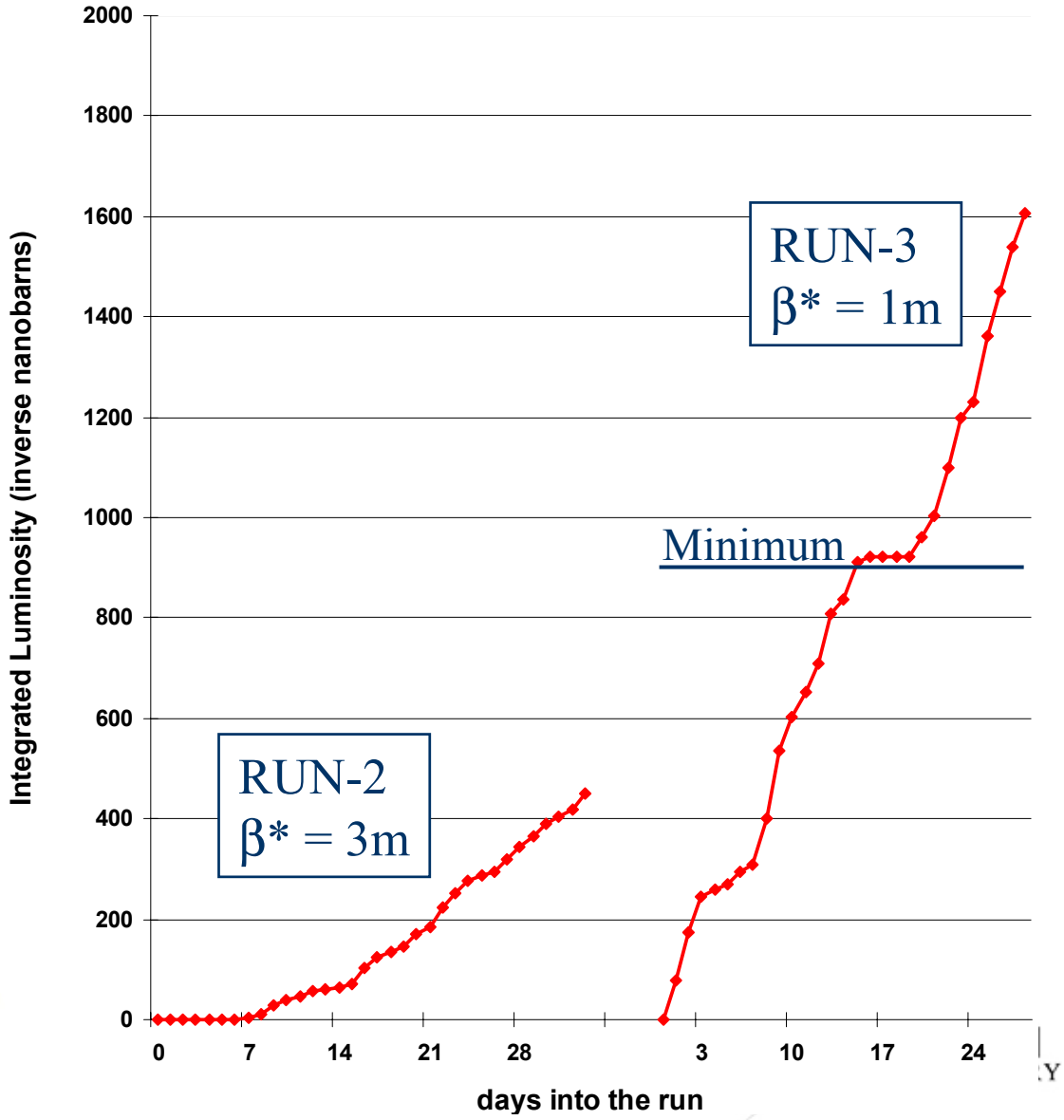
Delivered integrated p-p Luminosity

- Luminosity determined from Zero Degree Calorimeters (ZDC) that were calibrated with Vernier scans.
- Luminosities are similar for STAR and PHENIX with $\beta^* = 3m$ in Run-2 and 1m in Run-3
- Days shown are from start of physics data taking.



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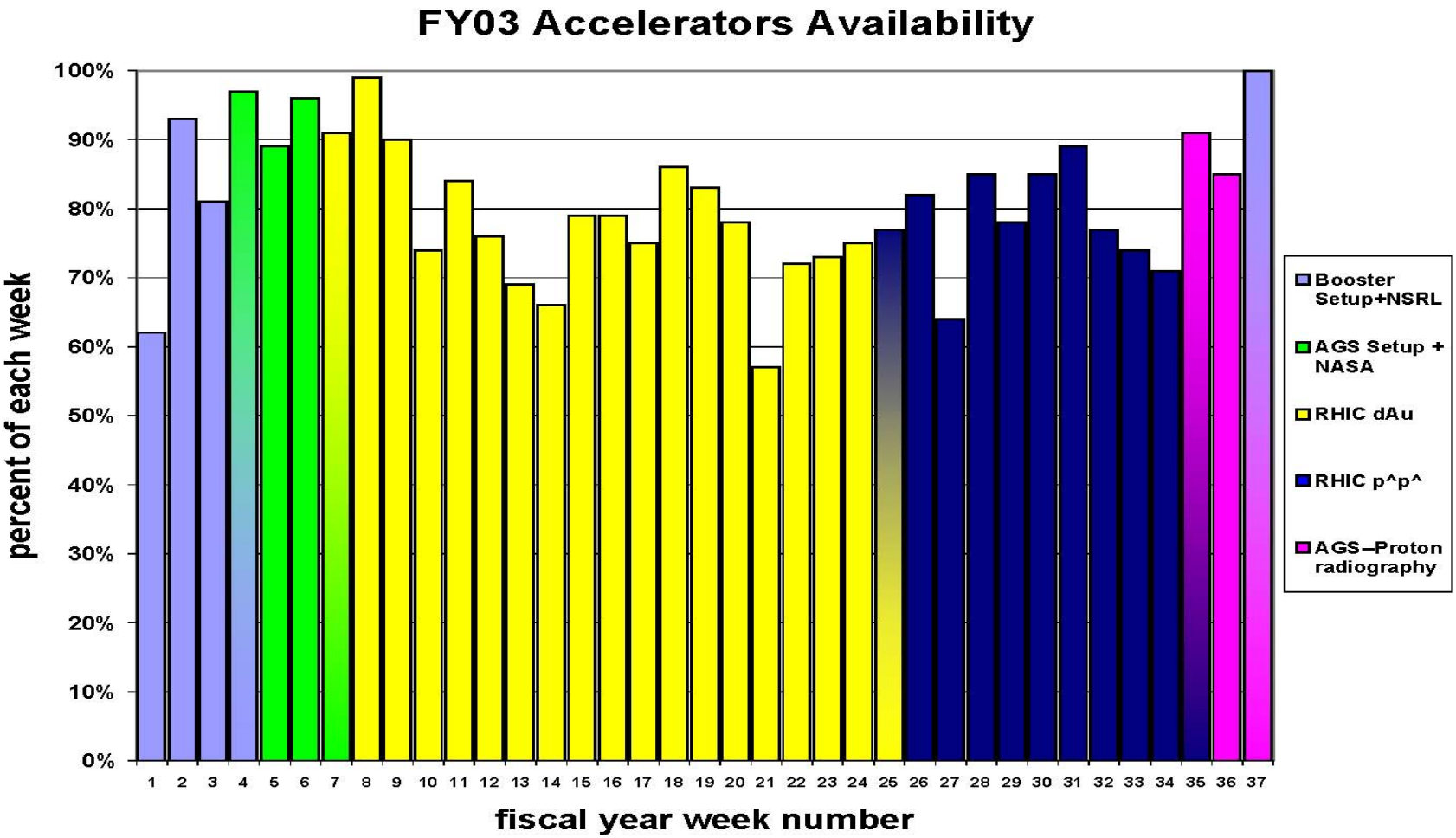
Availability= Running / Running + Unscheduled Downtime

Running=Physics+Machine Development+Beam Studies+Machine Setup+ Experimenter Setup



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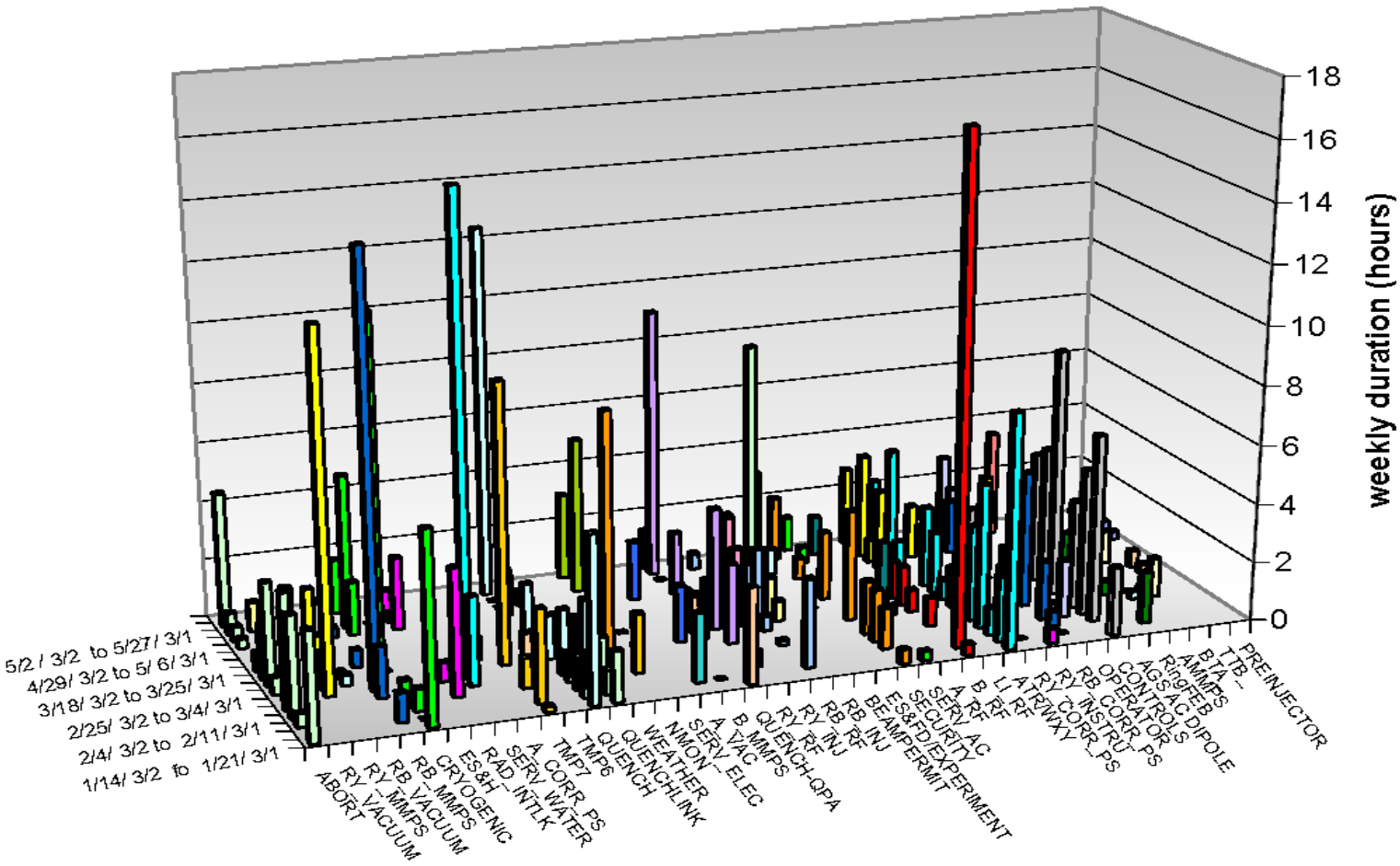
FY03 Integrated Failures (> 1 hr) by System -- During Physics Operation



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RHIC User Institutions

Abilene Christian University
Academia Sinica
Argonne National Laboratory
Argonne National Laboratory
Banaras Hindu University
Bhabha Atomic Research Centre
Brookhaven National Laboratory
Carnegie Mellon University
Center for Nuclear Study (CNS-Tokyo) China Institute of Atomic Energy
City College of New York
Columbia University
Creighton University
Cyclotron Application Laboratory
DAPNIA
Ecole Polytechnique/IN2P3-CNRS Palaiseau France
Florida State University
Fysisk Institutt
Georgia State University
Hiroshima University
Indian Institute of Technology
Indiana University
Institut de Recherches Subatomiques (IReS) de Strasbourg
Institute for Nuclear Studies Warsaw Poland
Institute of High Energy Physics (IHEP-Protvino or Serpukhov)
Institute of High Energy Physics Beijing
Institute of High Energy Physics Protvin
Institute of Modern Physics Lanzhou
Institute of Nuclear Physics Cracow Poland
Institute of Nuclear Physics Krakow
Institute of Particle Physics Wuhan
Institute of Physics Bhubaneswar
Instituto de Fisica da U. de Sao Paulo
Iowa State University and Ames Laboratory
IPN Orsay
ITEP Moscow Russia
Jagellonian University
Johns Hopkins University
Joint Institute for Nuclear Research (Dubna)
Kangnung National University
KEK Institute for High Energy Physics
Kent State University
Korea University
Kurchatov Institute
Kyoto University
Laboratory of High Energy Physics Dubna
Lawrence Berkeley Laboratory
Lawrence Livermore National Laboratory
LIR-Palaiseau

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RHIC User Institutions

Los Alamos National Laboratory
LPC-Clermont
Lund Universit
Massachusetts Institute of Technology
Max-Planck-Institut fuer Physics
Michigan State University
Moscow Engineering Physics Institute (MEPHI) Moscow Russia
Myong Ji University
Nagasaki Institute of Applied Science
National Central University Taiwan
Nevis Laboratory
New Mexico State University
New York University
Oak Ridge National Laboratory
Ohio State University
Panjab University
Particle Physics Laboratory Dubna
Pennsylvania State University
PNPI: St. Petersburg Nuclear Physics Institute
Purdue University
Rice University
RIKEN Inst. for Physical & Chemical Research
Seoul National University
Shanghai Institute of Nuclear Research
Space Sciences Laboratory
State U. of New York at Stony Brook
SUBATECH Ecole des Mines
SUBATECH Nantes
Texas A & M University
Tokyo Institute of Technology
Tsinghua University
Universitetet i Bergen
University of Alabama at Huntsville
University of Birmingham
University of Bucharest
University of California – Riverside
University of California Davis
University of California Los Angeles
University of Copenhagen
University of Frankfurt
University of Illinois at Chicago
University of Jammu
University of Kansas

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RHIC User Institutions

University of Muenster
University of New Mexico
University of Oslo University of Rajasthan
University of Rochester
University of Sao Paulo
University of Science and Technology of China
University of Tennessee
University of Texas at Arlington
University of Texas Austin
University of Tokyo
University of Tsukuba
University of Washington
Valparaiso University
Vanderbilt University
Variable Energy Cyclotron Centre
Warsaw University of Technology
Waseda University
Wayne State University
Weizmann Institute
Yale University
Yonsei University

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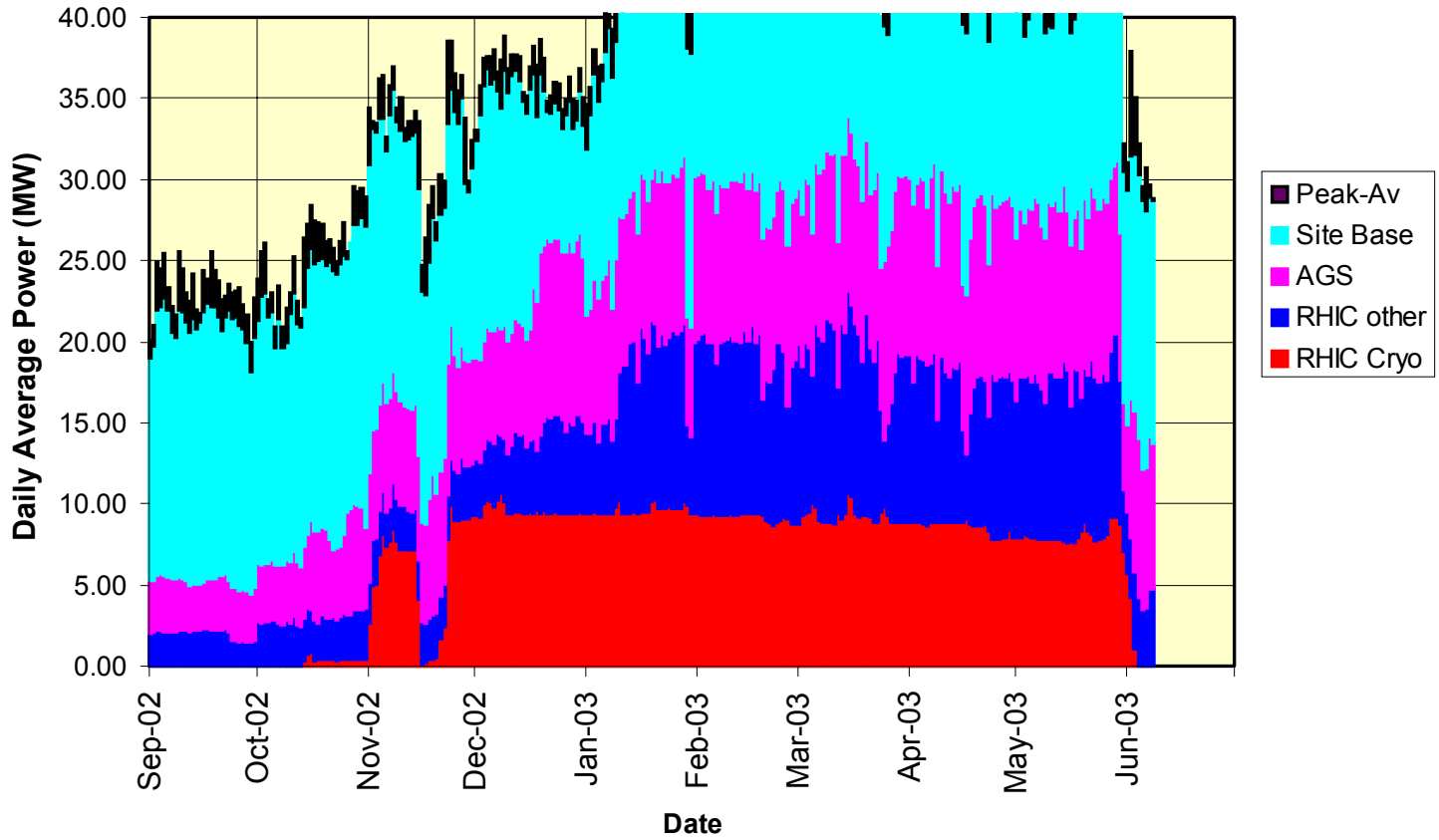
FACILITY CONCERNS AT PREVIOUS REVIEW

- SPIN ROTATORS OPERATIONAL (LONGITUDINAL POLARIZATION)
- LHe STORAGE SYSTEM & LN_2 COOLER OPERATIONAL
- REPAIR SIEMENS MG SET; OPERATIONAL
  - Massive failure on Aug. 3, 2001 after scheduled overhaul ($1.8M) at General Electric and returned to service on June 6. On line by by Sept. 30, 2002. Additional cost of~$1.4M.
  - Substantial impact on AGS polarization
- REPAIR CRYOGENIC VALVE BOXES
  - 12 valve boxes. 6 boxes have had leaks. Worst 2 COMPLETED
- REFRIGERATOR COMPRESSOR REBUILDS; OPERATIONAL
- PURCHASE SPARE TRANSFORMERS (Delayed due to funding)
  - MG set transformers are single point of failure for both Siemens & Westinghouse.
- INDUCED FLICKER FROM BOOSTER PULSING NOT AN ISSUE
- INFRASTRUCTURE (selected items only, time and funds)
  - Cryo system painting ongoing (environmental hazard and likely failure point)
  - RHIC berm, paving started. Road dust is winding up in power supplies etc.
  - Support building and experiments cooling, humidity control (ongoing)
- POWER SUPPLY PERFORMANCE (not a major problem now)

CONCERNS

- Operations costs
  - Power cost rate is uncertain
    - NYPA power agreement ends in FY2005
  - Cryo system is undergoing an engineering review and modifications
    - JLab has been an excellent resource
    - Already reduced usage from 10MW to 7.5MW usage
    - Estimating that 6MW operating power is possible
      - Modifications costing is work in progress
    - 4MW = $40K/week savings

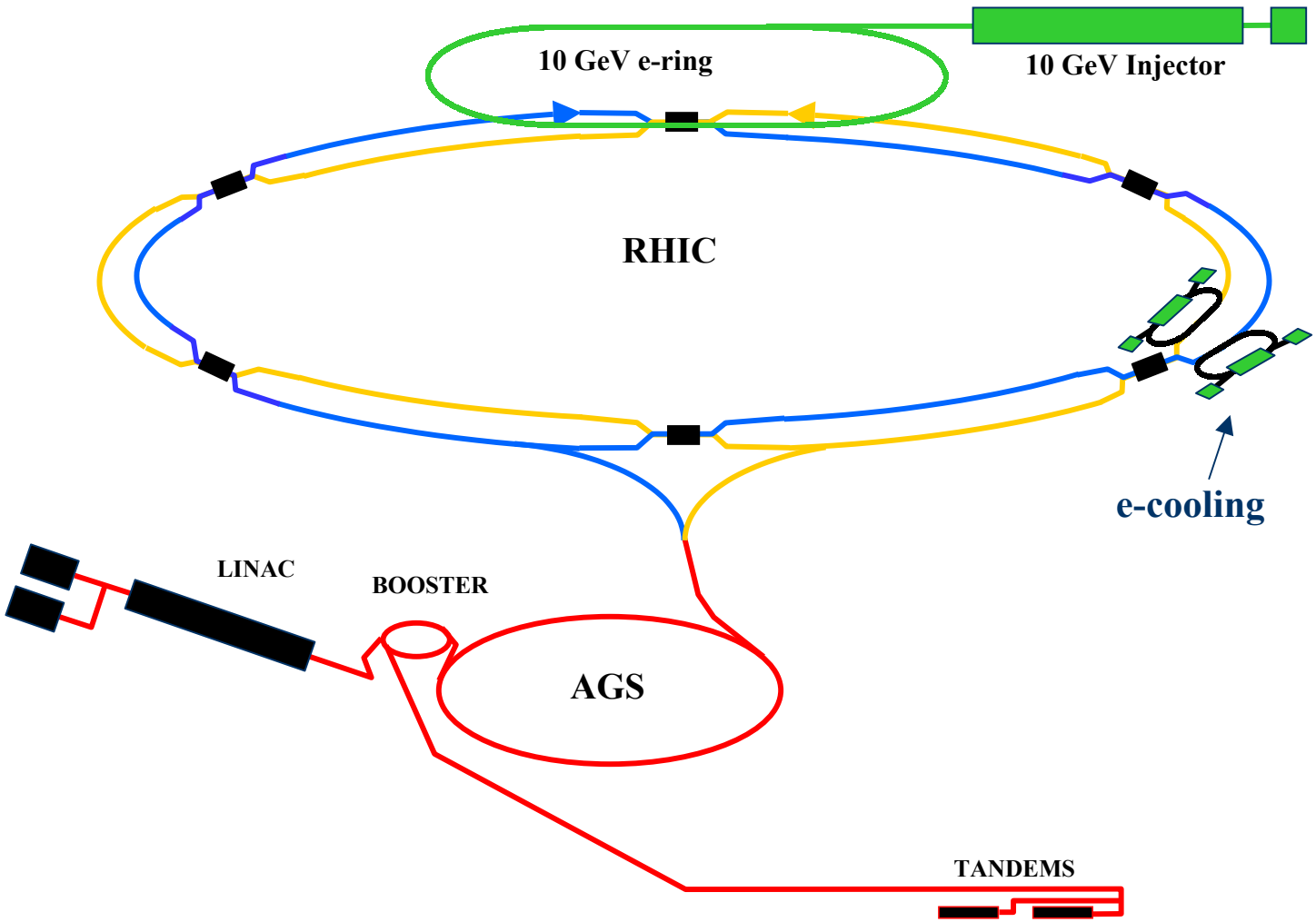
BNL Energy Use FY 2003



- Hardware
  - Ice ball formation on superconducting magnet power feeds and quench detection system (Harrison)
  - Future DX magnet replacement a possibility (Harrison)
  - Snake failure this run (Harrison)
    - Undergoing a post mortem
      - Magnet, quench protection system?
  - Linac 7835 power tubes
    - Sole vendor (Burle) has production problems
      - Loaned 2 tubes to Fermilab. They ran out of spares.
      - We have 1 spare tube and 5 on order
    - Options
      - Restart BNL construction effort, replace RF system, buy a lot of spares
      - All require substantial funding ($3-10M)
      - Alternatives being studied
  - Move alcove equipment to the surface to improve availability
    - Radiation upsets, equipment damage
    - Repair equipment without ring entry

- **RHIC Construction and R&D** (Roser presentation)
  - polarized jet nearing completion
  - stochastic cooling (longitudinal)
    - FY2004 test
  - intensity dependent vacuum desorption, RHIC beam intensity limit
    - NEG vacuum pipe test in FY2004 (60m of warm section)
  - electron-cooling of RHIC ions
    - produce a "CDR" by summer 2004
  - eRHIC design
    - ZDR by January 2004
    - MIT / BATES a major collaborator
  - EBIS R&D completed
    - Technically ready for construction
    - Proposal submission to DOE is underway

eRHIC



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OTHER PROGRAMS

C-AD Other Program Areas

Other Major Programs

	FY 2002	FY 2003	FY 2004	FY 2005
BNL/NASA				
BAF Project	$9,824	$2,800	$0	$0
NSRL Operations *	0	1,016	3,126	3,235
NASA AGS OPS *	1,092	1,238	1,280 (?)	1,325 (?)
Total NASA	$10,916	$5,054	$4,406	$4,560
Effort - FTE	*34*	*17*	*14*	*14*
BNL/ORNL SNS	$29,445	$29,060	$14,400	$2,900
Effort - FTE	*100*	*102*	*66*	*15*
All other work	$780	$2,671	$592	$590
Effort - FTE	*6*	*2*	*1*	*1*
Total C-AD Oper. Cap. AIP	$131,371	$133,090	$117,488	$135,338
Effort - FTE	*493*	*484*	*435*	*427*

* **Additional funds for Medical and Biology not included.**

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- **AGS**
  - RSVP (NSF HEP (Construction pending $150M, FY2005-6), $13M / year operations)
  - E949 operations (NSF HEP?), requested
  - E821 (g-2) upgrade (NSF HEP?), under discussion
  - Proton Radiography (NNSA), ongoing
  - Radiobiology (NASA, additional to NSRL), likely

AGS USER INSTITUTIONS

Brookhaven National Laboratory
Institute for Nuclear Research
Kyoto University, Japan
Thomas Jefferson National Accelerator Facility
TRIUMF, Canada
Virginia Polytechnic Institute
Yale University
University of Cincinnati
University of New Mexico
University of Virginia
University of Zurich

Institute for Nuclear Research, Moscow
New York University
University of California at Irvine
University of Houston
University of Pennsylvania

Bechtel Nevada
Lawrence Livermore National Laboratory
Los Alamos National Laboratory

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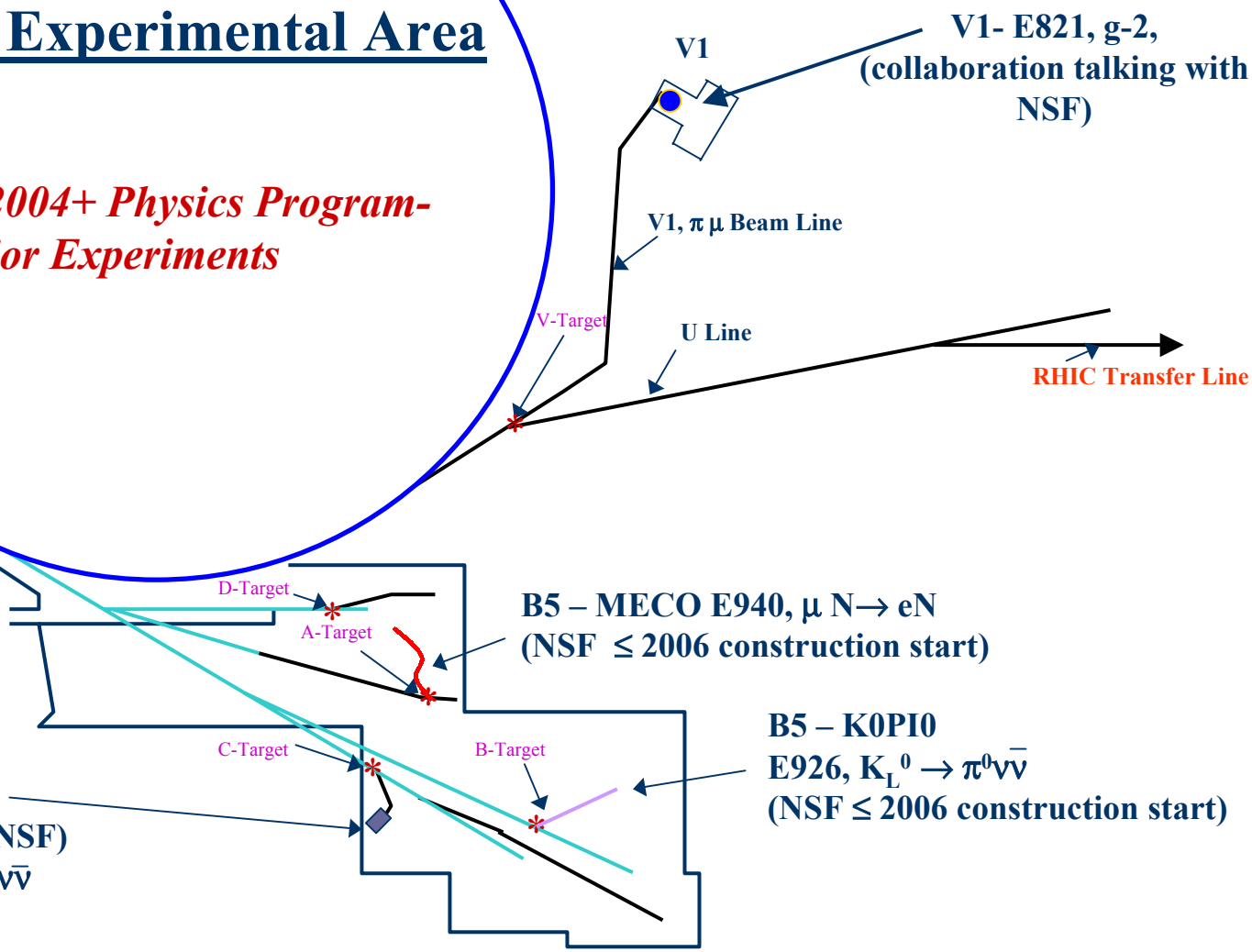
AGS Experimental Area

FY2004+ Physics Program-
Major Experiments



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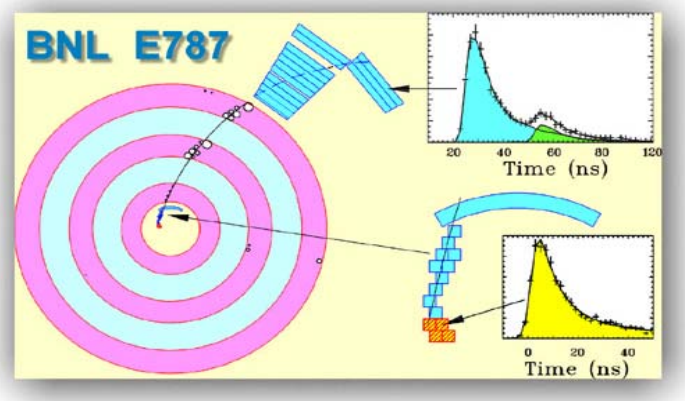
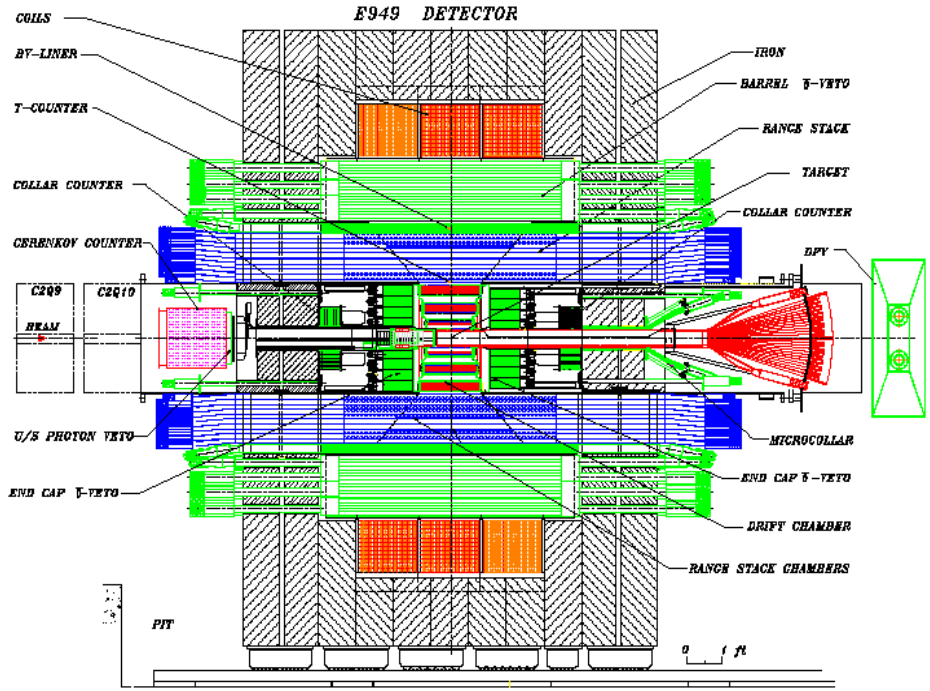
E949 – Measurement of B($K^+ \to \pi^+ \nu \bar{\nu}$)





Collaborating institutions:

Japan --- **Fukui University, JAERI, KEK, Kyoto University, National Defense Academy, Osaka University, RCNP**

US --- BNL, FNAL, University of New Mexico, Stony Brook University

Canada --- University of Alberta, University of British Columbia, TRIUMF

Russia --- IHEP, INR

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E949 Progress in 2002-2003

- E949 data from 12 weeks in 2002 will approach E787 sensitivity (~80 weeks)
- Result from high momentum search region expected in summer 2003
- Results from full $\pi\nu\nu$ spectrum and for $\pi^0 \to \nu\bar{\nu}$ and $K^+ \to \pi^+\gamma\gamma$ expected in 2004
- The E949 Detector has been shown to work as expected & collaboration remains intact – E949 is ready to complete its running time

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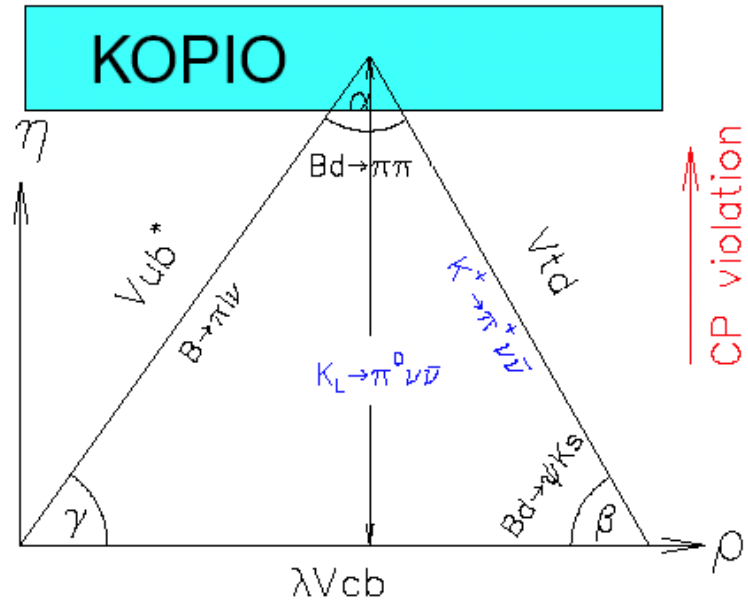
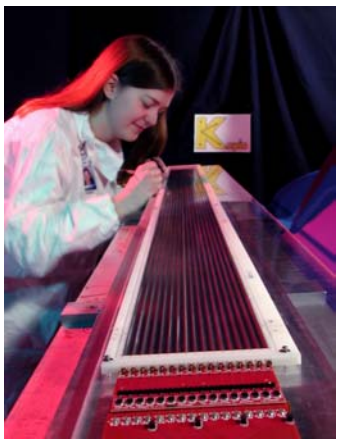
KOPIO – CP-violation experiment

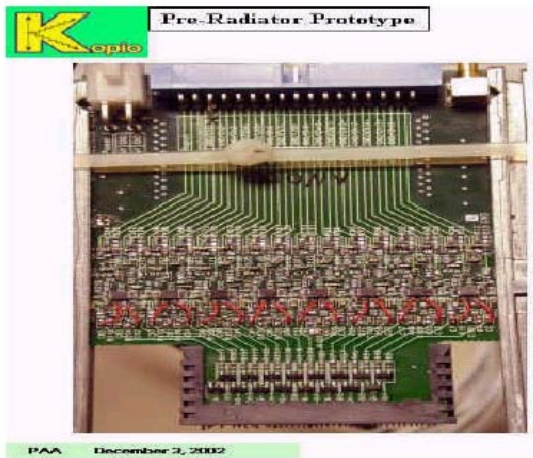
Measurement of the process $K_L \to \pi^0 \upsilon \bar{\upsilon}$ to determine CKM η to 10%

Scheduled for FY2006 construction start, Currently in R&D.

Much progress in 2002-03:
- Collaboration augmented
- Successful tests of AGS running mode & beam instrumentation
- Extensive prototype studies --







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The MECO experiment will search for muon to electron conversion with a sensitivity of 1 event at a branching fraction of 1×10^{-16}. This experiment will provide an extremely powerful probe of lepton flavor violation and physics beyond the Standard Model.

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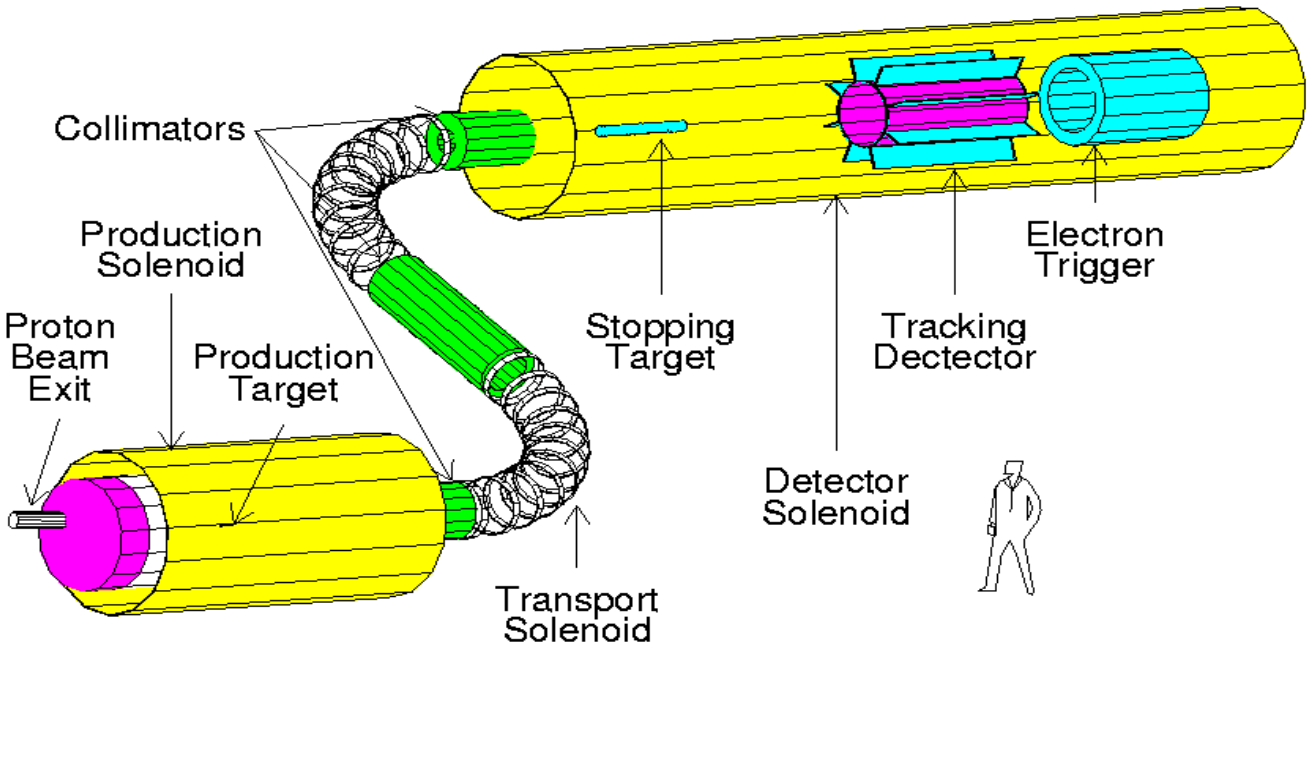
MECO Detector



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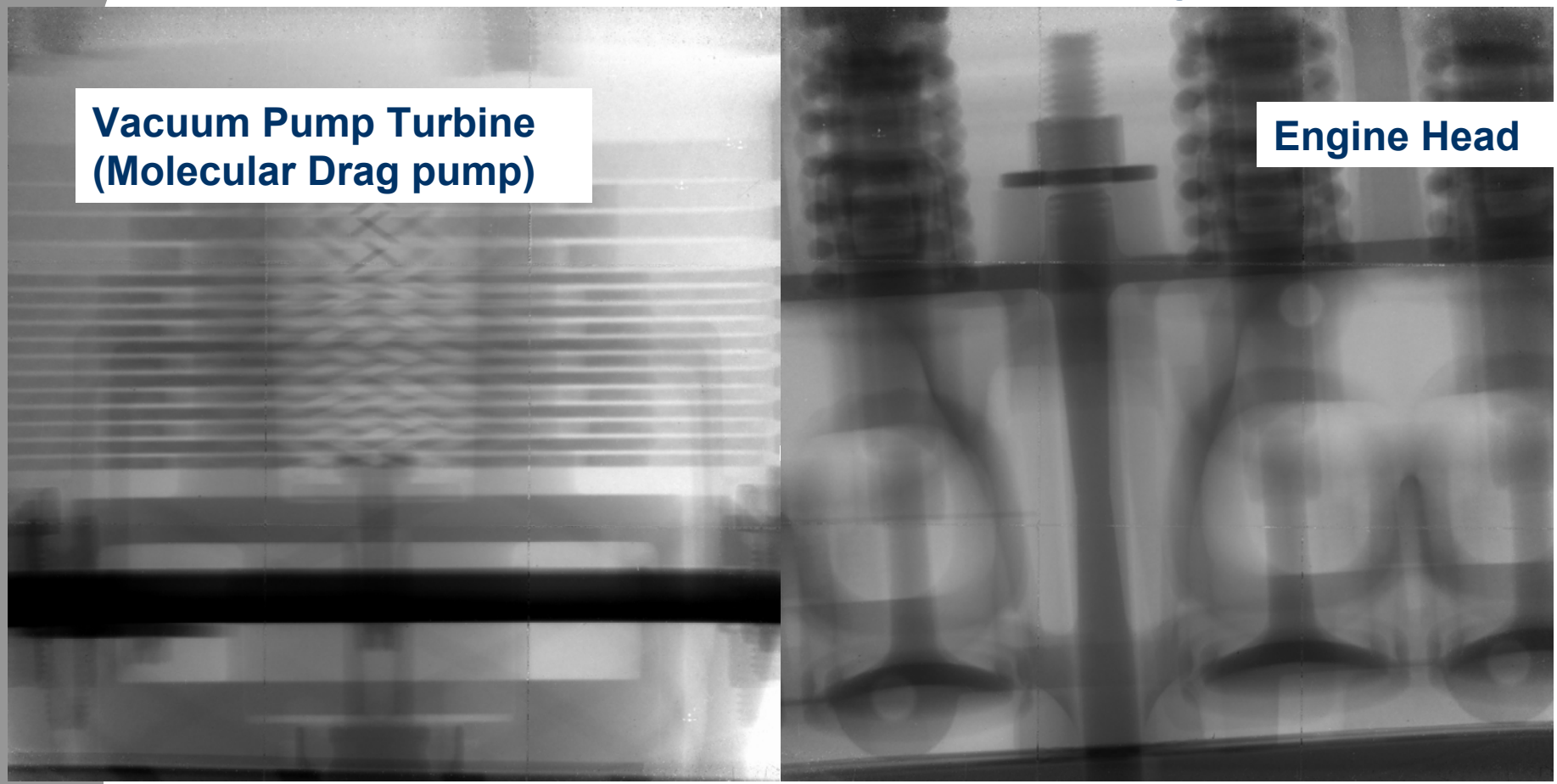
Proton Radiography at 24 GeV (Giga Electron Volts)

Brookhaven National Laboratory



Experiment 963 Radiographs by Los Alamos National Laboratory

George A. Greene (BNL) & Matthew M. Murray (LANL) power point file = pcPRAD57\Exp963\Industrial\Turbo-Head-June2003

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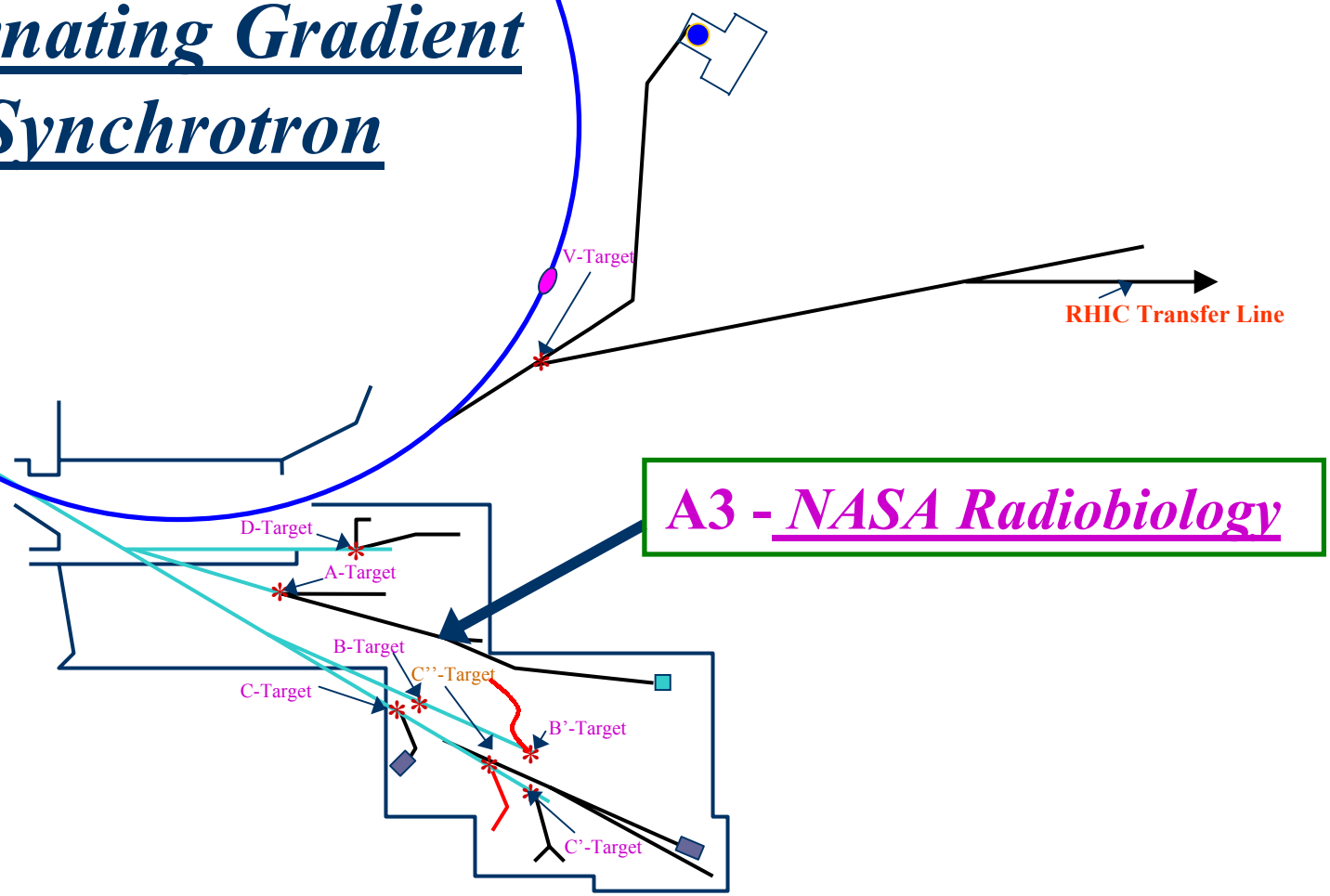
Alternating Gradient Synchrotron



A3 - *NASA Radiobiology*

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- **Tandem**
  - Commercial Users ($1M yearly sales)
  - Electronic upset, micropore filters etc.
  - Scheduled around RHIC and NSRL ion programs

TANDEM User Institutions

Actel Corporation
Aerospace
ALCATEL Espace (France)
Johns Hopkins University (APL)
BAE Systems
BNL
CEA-DIF (France)
CEA (France)
Daimler Chrysler
Data Device Corp.
GDIS General Dynamic
HIREC Corp. (Japan)
HIREX (France)
Honeywell (SASSO)
Honeywell (SSEC)
Honeywell International
Intersil Corporation
International Rectifier Corp.
ITT Aerospace
Jet Propulsion Laboratory (JPL)
JPA Electronics
Lambda Advanced Analog
Lockheed Martin Aerospace Corp.
Lockheed Martin CPC
Lockheed Missiles & Space Corp.
Lockheed Martin Corporation
Matra MHS (France)
Maxwell Technologies
Mitsubishi Heavy Industries (Japan)
Myers and Associates
NASA
NASA (Label)
Naval Research Lab (NRL)
NAVSEA Crane Division
NEC Corp. (Japan)
Pall Corporation
Raytheon
Sandia National Laboratories
SNS
Space Electronics
Stauber Enterprises
TRAD (France)
TRW
United Tech Microelectronics Ctr
University of Arizona
University of Maryland
University of NM (NASA/MERC)
Vanderbilt University
VPT Inc.
Whatman Nuclepore

28 US Companies
5 US Universities
6 European Companies
8 US Agencies and Laboratories

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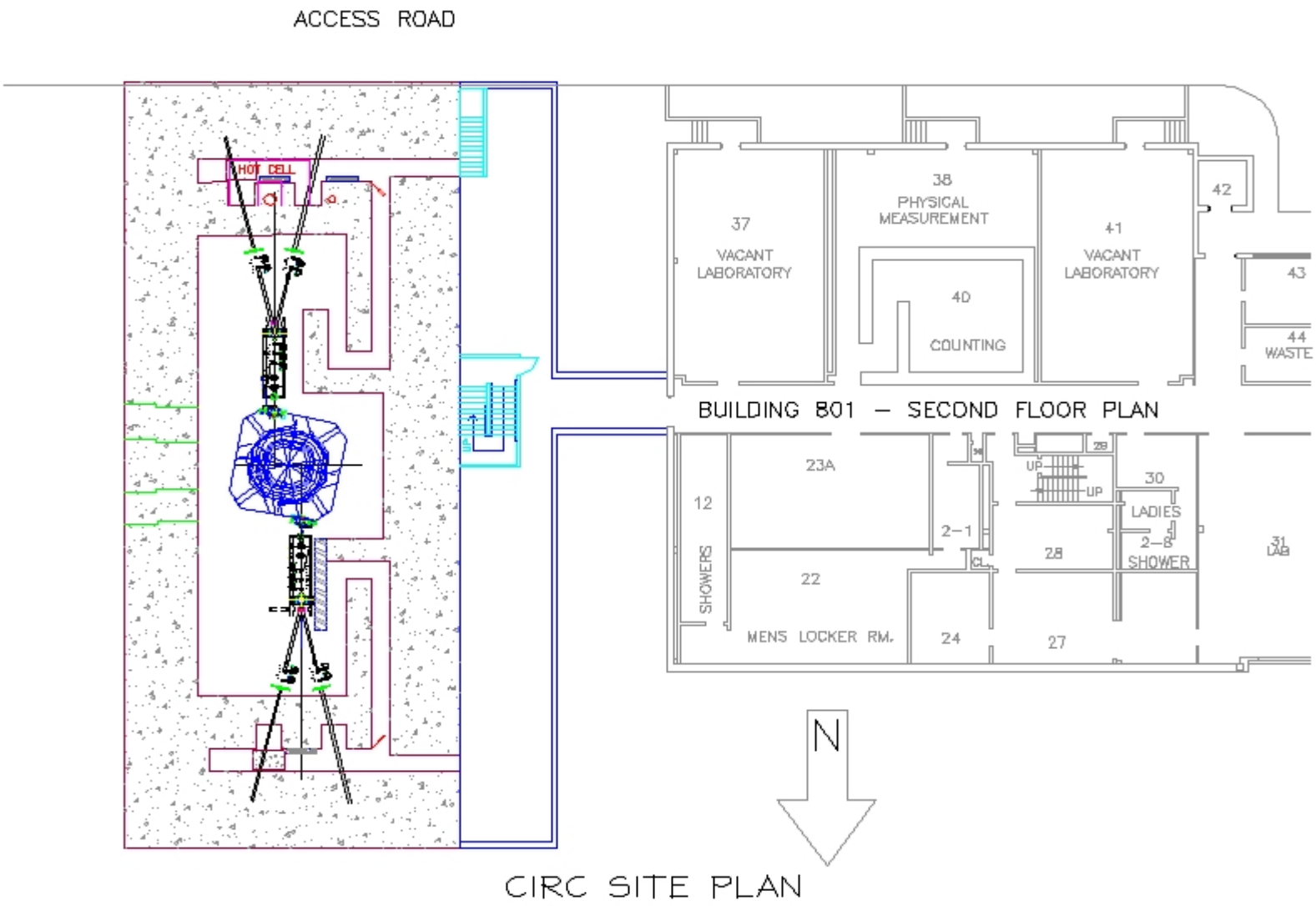
- **Linac**
  - BLIP isotope production (DOE-NE, *continued operations are problematic, parasitic to linac operations, DOE HEP has terminated proton operations*)
  - Typically supports linac operation on an incremental basis, yet is major consumer of protons
  - Cyclotron Isotope Research Center, CIRC (DOE-NE, pending, $38M) is proposed to replace BLIP
    - 70 MeV, 2 ma. cyclotron

CYCLOTRON ISOTOPE RESEARCH CENTER (CIRC)



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- **Booster**
  - NASA Space Radiation Laboratory (NASA, CD4 completed, **on time and below budget ($34M)**, operations started July 7, 2003, $5.7M /year, incl. Medical and Biology Depts.), *inauguration ceremony dates ~ Oct. 14,15 or 22*

NASA RADIOBIOLOGY PROGRAM AT BNL

A CENTER FOR RADIOBIOLOGY RESEARCH

- ALTERNATING GRADIENT SYNCHROTRON
  - Research program begun 1995
  - 9 experimental runs to date
- TANDEM VAN DE GRAAFF
  - Applications program begun in 1988
- NATIONAL SPACE BIOMEDICAL RESEARCH INSTITUTE
  - Consortium member (1999)
- NASA SPACE RADIATION LABORATORY (NSRL, $34M)
  - Construction begun 1999
  - First beam extracted October 2002
  - Project complete June 2003
  - **Operations began July 2003**

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NASA User Institutions

Alabama Agricultural and Mechanical University, AL
APL, John Hopkins University, MD
Bemidji State University, MN
Brookhaven National Laboratory, NY
Case Western Reserve University, OH
Cole Eye Institute, OH
Colorado State University, CO
Columbia University, NY
Duke University, NC
Georgetown University Medical Center, DC
Human Nutrition Research Center on Aging, MA
John Hopkins University, MD
Lawrence Berkeley National Laboratory, CA
Loma Linda University Medical Center, CA
Los Alamos National Laboratory, NM
MRC, England
NASA Headquarters, DC
NASA, John Space Center, TX
NASA, Johnson Space Flight Center, TX
NASA, Langley Research Center, VA
National Institute of Health, Rome, Italy
National Institute of Nuclear Physics, Bologna, Italy
National Institute of Radiological Sciences, Japan
National Space Biology Research Institute, TX
National Space Biomedical Research Institute, TX
New York University Medical Center, NY
NSCORT, LBNL-CSU, CA
Pacific Northwest National Laboratory, WA
Prairie View A&M University
SRI International, CA
SUNY at Stony Brook, NY
Texas A&M University, TX
Thomas Jefferson University, PA
University "Federico II", Napoli, Italy
University of California, Riverside, CA
University of California, San Francisco , CA
University of Maryland, Baltimore County, MD
University of Maryland, MD
University of New South Wales, Sidney, Australia
University of Pennsylvania, PA
University of Puerto Rico, PR
University of Rome, Thor Vergara, Italy
University of Texas Health Sciences at San Antonio, TX
University of Texas Medical Branch, TX
University of Tokyo, Japan
USAF, Armstrong Laboratory, TX
Virginia State University, VA
Washington State University, WA

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WHY RADIATION BIOLOGY RESEARCH AT BNL? AS EXPLAINED BY A PHYSICIST!

- **Going into space is not what is portrayed in Star Trek**

- **What are the space radiation risks for exploration missions?**
  - GCR (galactic cosmic rays)
    - Cancer, latent effects such as cataracts, hereditary effects and neurological disorders
    - 3 year mission to deep space, every cell will be struck by at least one GCR particle
  - SPE (solar particle events, protons)
    - Potentially life threatening

- **How do you mitigate the space radiation risks?**
  - Sensing of solar events: When should you seek shelter?
  - Shielding: What shelter is effective?
  - Chemical and biological countermeasures: What can you ingest etc. to counteract any radiation damage?

protons to gold

slow extracted

40-3000 MeV / nucleon

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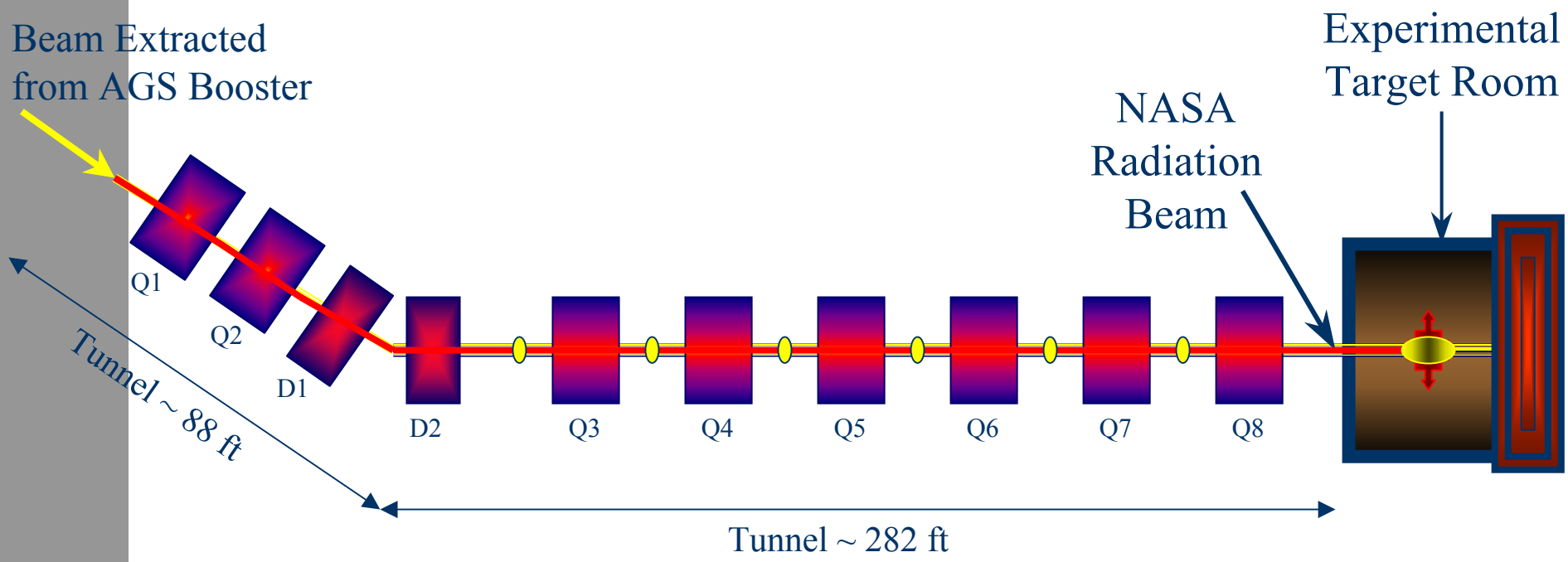
NASA Space Radiation Laboratory (NSRL)

Brookhaven National Laboratory (BNL)



NSRL receives the radiation beam extracted from AGS through a ~ 370 ft long tunnel covered under a concrete shield of ~ 15 ft thickness and fine tuned with eight quadrupole (Q) and two diverter (D) magnetic devices.

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Courtesy of NASA JSC

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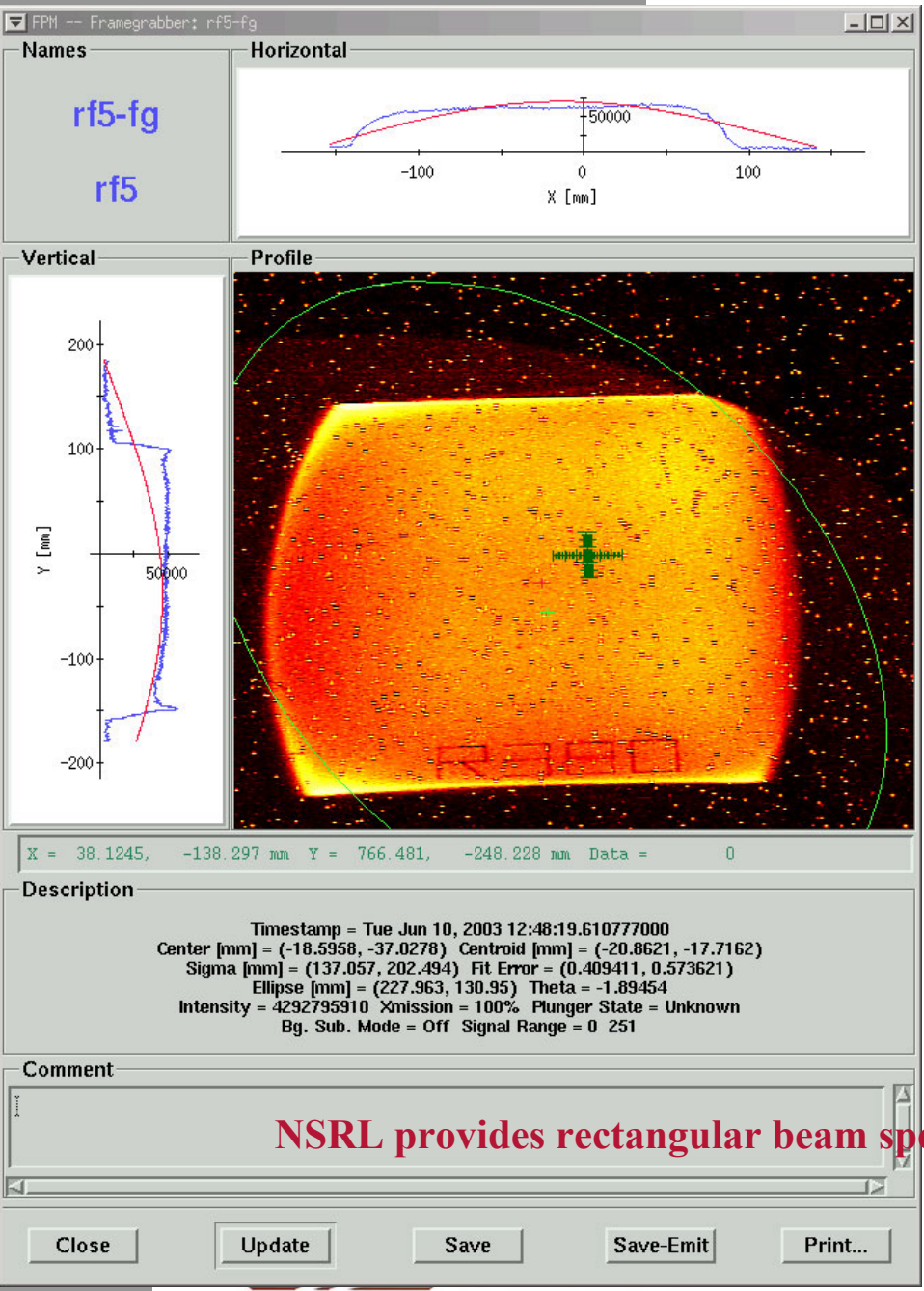
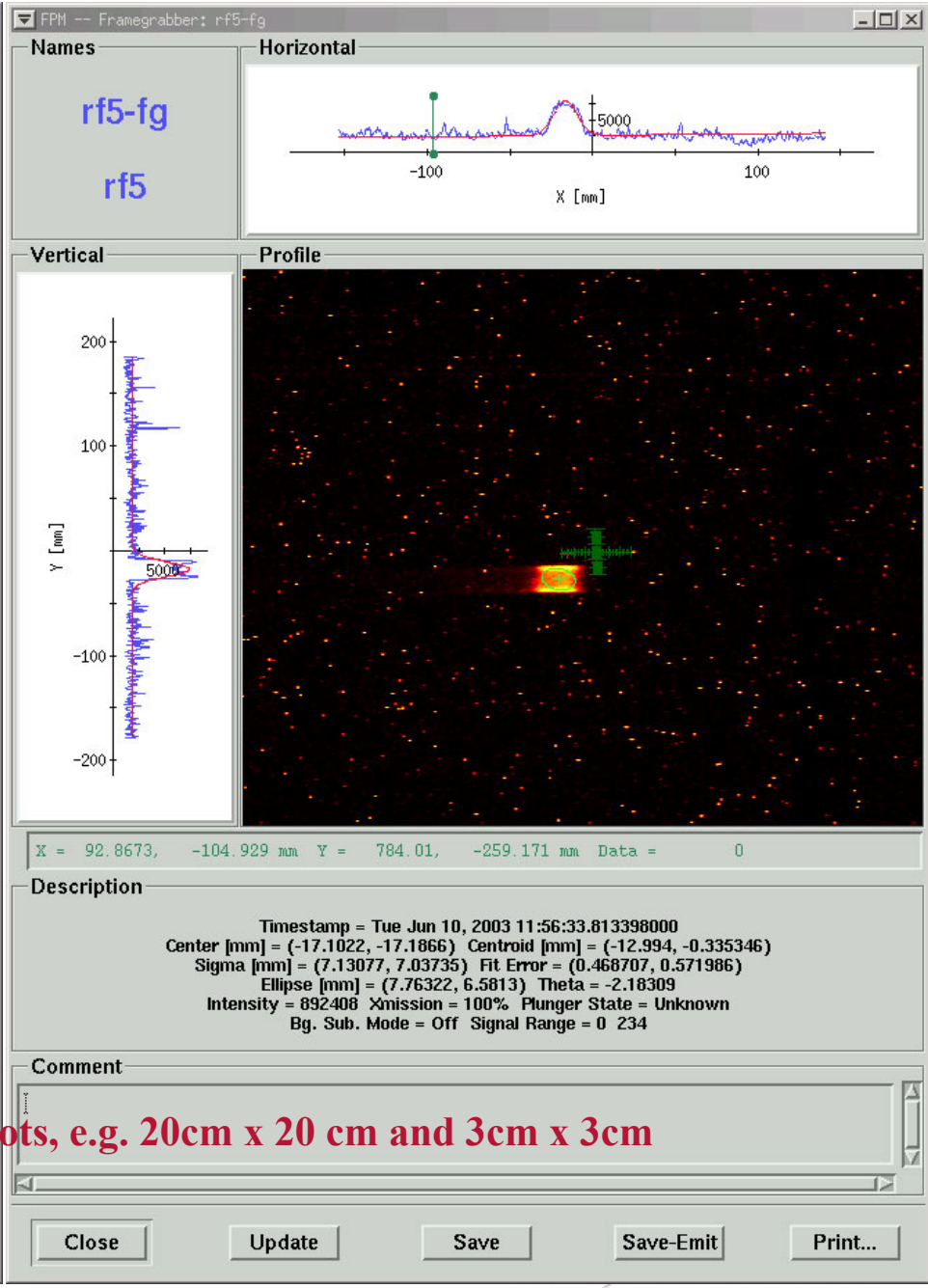
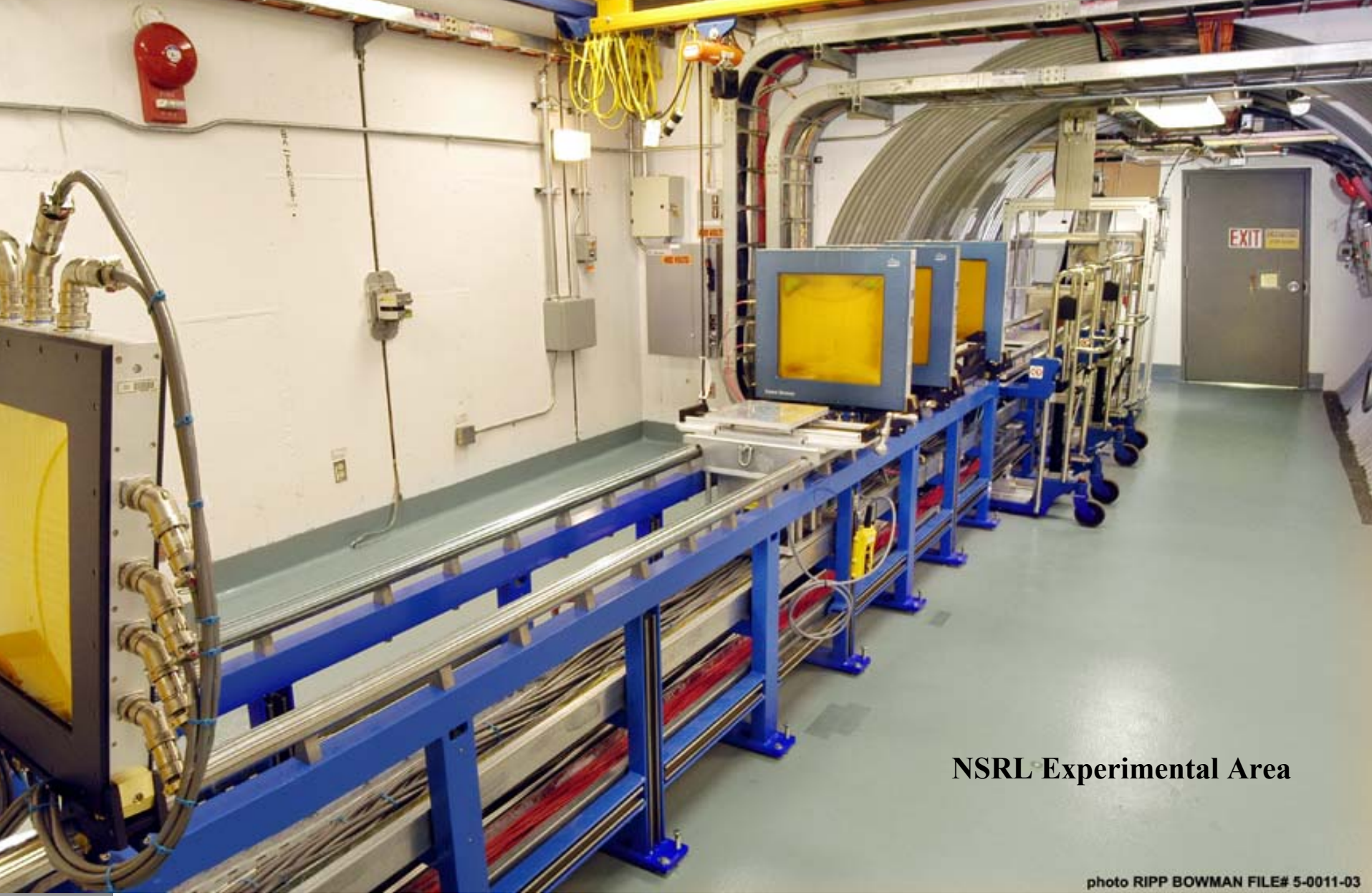




NSRL provides rectangular beam spots, e.g. 20cm x 20 cm and 3cm x 3cm



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- **Projects**
  - Spallation Neutron Source accumulator ring and beam transports (DOE-BES, complete FY2005, $110M)

Spallation Neutron Source

- 60 Hz repetition rate, 1.5×10^{14} per pulse, 1.4 MW proton facility
- In its 5th year of a 7-year construction cycle
- H^- Source, RFQ, DTL, CCL, SRF linac, Accumulator, Hg-target

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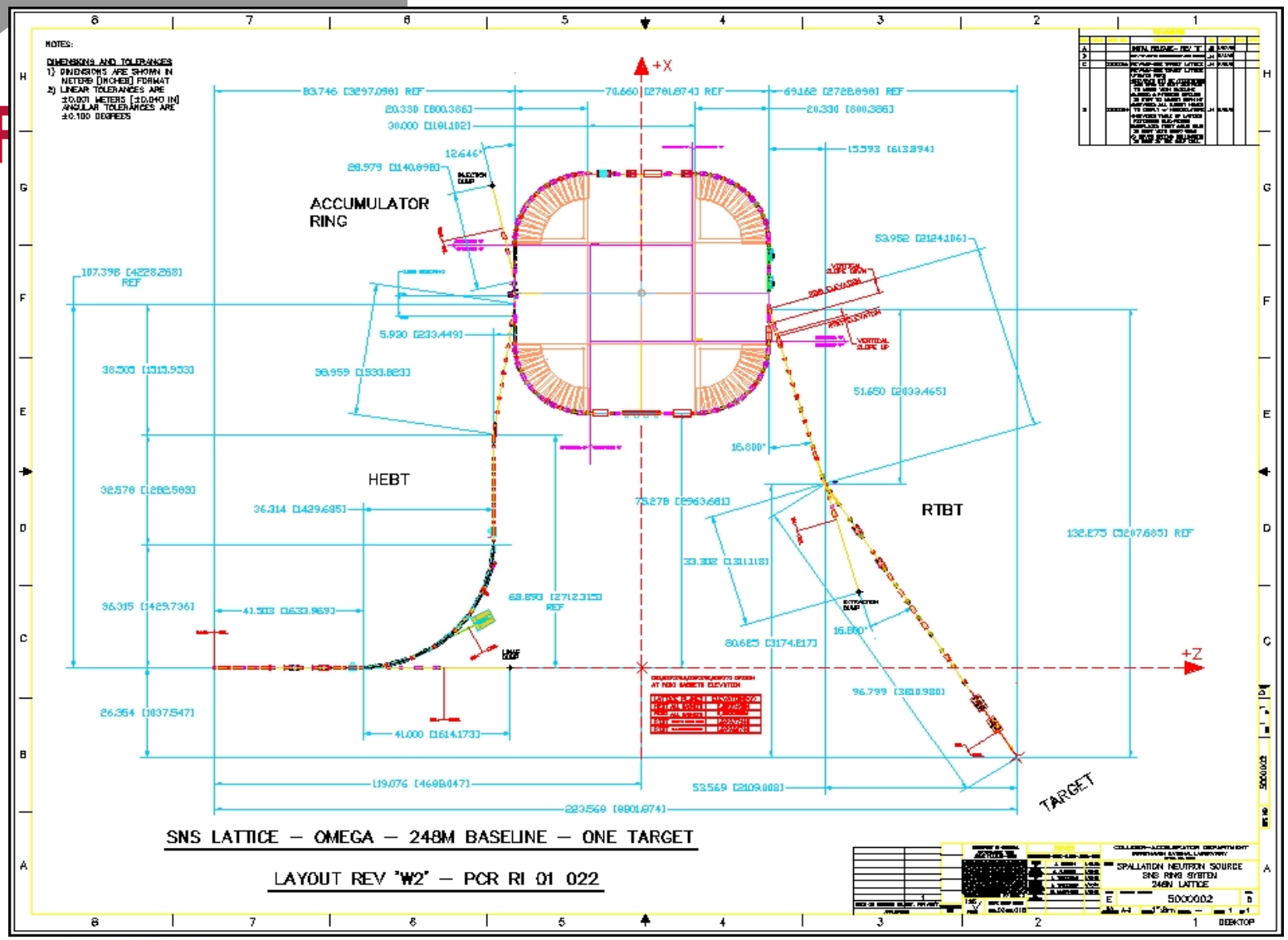

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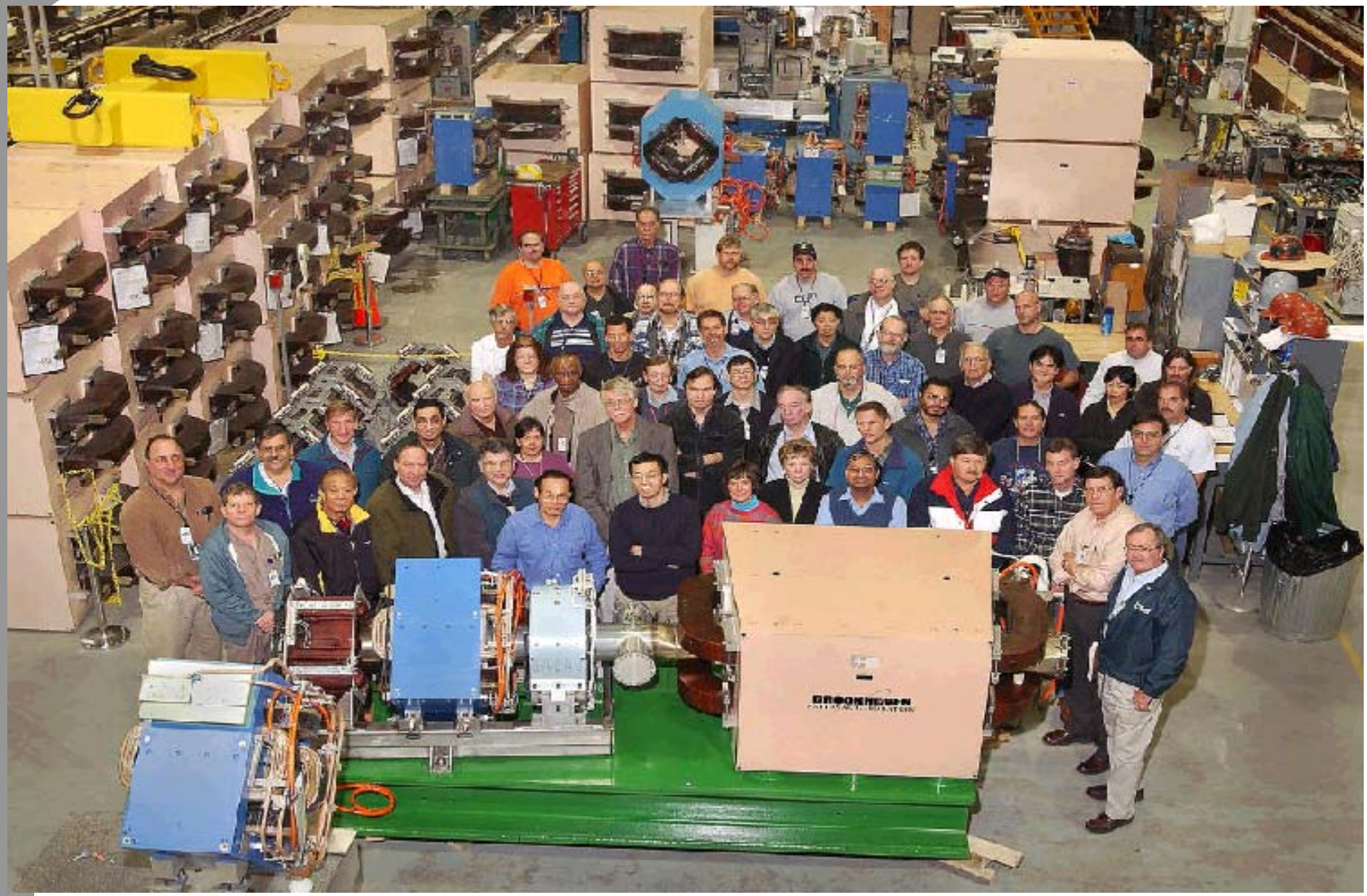
First Half-Cell before Shipment to ORNL (Nov. 2002)



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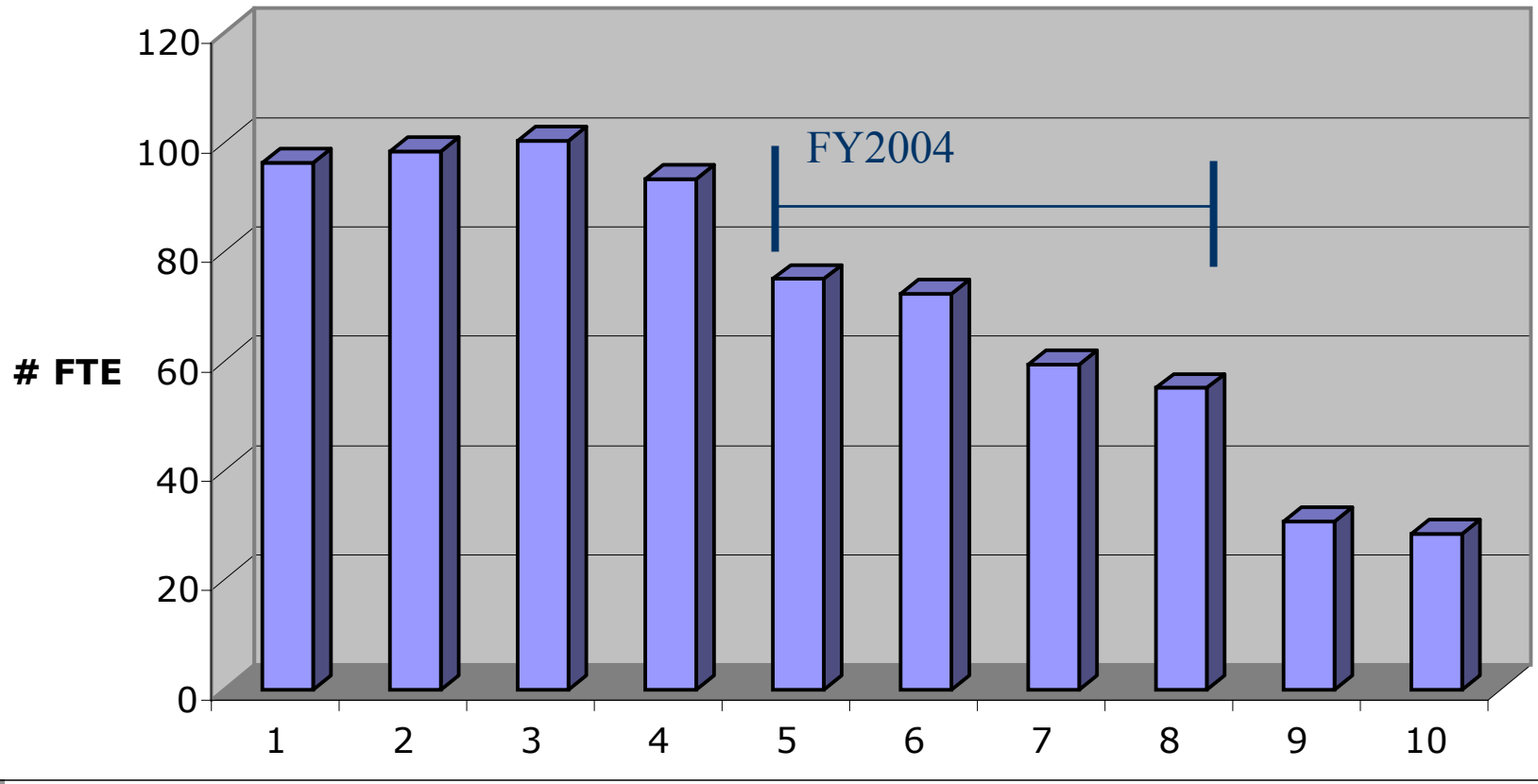
FY03-FY05 SNS FTE Projectic (per quarter)



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SUMMARY

- FY2003 RHIC physics results have been extraordinary
- Collider continued to improve its performance
- Physics requests to supply various species and energies requires more beam time for C-A to provide the desired machine performance. We need to run 37 weeks per year.
- We look forward to another successful year in FY2004
- A special thanks to the DOE NP office for their enthusiastic and sustained support

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